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EFFECTS OF CARBON DIOXIDE LASER RADIATION ON BONE. AN INITIAL R--ETC(U)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study of the effects of carbon dioxide laser radiation on bone was conducted. Results indicated that wounds produced by a CO_2 laser have a retarded rate of healing when comparable size produced by a surgical bur. The retarded healing is probably due to the presence of a black, carbonaceous surface material resulting from the thermal effects of laser radiation.

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EFFECTS OF CARBON DIOXIDE LASER RADIATION ON BONE:
AN INITIAL REPORT

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An enthusiastic interest in the use of laser radiation as a potential surgical tool has persisted since the development and introduction of the carbon dioxide (CO_2) laser. Current instruments can deliver a high intensity, directional, easily controlled beam that is almost completely absorbed by biological tissue. The result is vaporization of a focal mass of tissue with minimal effect on

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The opinions contained in this article are those of the authors and are not to be construed as official or as representing the views of the Department of the Army.

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In conducting the research described in the manuscript, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Sciences - National Research Council.

the surrounding tissues.[5]

The hemostatic effects of the CO_2 laser make it particularly attractive for use in surgery. The capacity of the laser to coagulate small blood vessels and capillaries has been well established[1,4,11,12] as has been its effectiveness in the sterilization of infected and necrotic lesions.[6,10,11]

Additional studies[8,13] have suggested that the CO_2 laser is of potential value in orthopedic surgery for the treatment of osteomyelitis and biopsy of suspected malignant neoplasms. Findings from these studies have stimulated the need for investigations into the effects of CO_2 laser radiation on bone.

REVIEW OF THE LITERATURE

The earliest investigations into the effects of laser radiation on bone utilized pulsed ruby lasers. It was found that, with sufficient energy, bone could be excavated by the beam after repeated strikes in the same area.[8] However, scattering of the beam occurred upon striking the bone suggesting that the biological effects could not be confined to the focal area of the impact.[3] Additionally, shock waves of great amplitude were produced which may damage surrounding tissue.[7]

In a preliminary investigation,[2] Goldman, et. al., consistently produced fat emboli when they irradiated the bones of rabbits with a ruby laser. They attributed their findings to the fact that high output pulsed laser systems generate thermally induced stresses and recoil pressures secondary to sudden vaporization of tissue.

Because of the limitations of pulsed laser instruments, investigators began using continuous wave systems such as the CO_2 laser.

Drilling and cutting of bone has been performed successfully in animals with the CO_2 laser.[8,9,14] The result is charred, carbonaceous, flaky surface material interspersed with tiny, whitish beads of calcium compounds.[11] Experimental osteotomies have been accomplished with the CO_2 laser and radiographic evaluation demonstrated no obvious detrimental effects.[14] Histologic evaluation of the effects of laser radiation on bone was not pursued in these investigations.

METHODS AND MATERIALS

Forty white, male, Walter Reed Strain laboratory rats were used in the investigation. The rats were anesthetized by an intraperitoneal injection of sodium pentobarbital (30mg/kg body weight). Both the left and right tibiae of each animal were surgically exposed by means of a 0.5 mm incision on the medial aspect of each lower leg. Utilizing a sterile technique, soft tissue was dissected and retracted to reveal a small area of bone.

The right tibia received a single impact of radiation delivered from a carbon dioxide surgical laser.* The laser beam was focused to a two millimeter spot at the impact site and was delivered with 30 watts of power for a duration of 0.5 second. The left tibia served as a control and received a hole produced by a number four round surgical bur in a straight, slow-speed handpiece. The bur hole extended through cortical bone and was irrigated and debrided with copious quantities of sterile saline. Following the procedure the surgical sites were closed with 000 polyester sutures.

The rats were sacrificed by means of an overdose of sodium

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*Coherent Medical, Palo Alto, California pentobarbital injected into the peritoneal cavity. The sacrifice schedule was in groups of ten at intervals of three, seven, fourteen, and twenty-eight days after the operation. Both tibiae were dissected, removed, and placed in ten percent buffered formalin. They were then grossly examined for microscopic evidence of tissue damage and healing. Following gross examination, the specimens were decalcified and stained with hematoxylin and eosin for histologic study.

RESULTS

THREE DAYS:

The bur wound (fig. 1) consisted of a cylindrical defect that was approximately one millimeter in diameter and 1.0-2.0 mm in depth. Damage induced by the bur consisted predominantly of mechanical disruption of tissue which produced a pronounced operative hemorrhage. The healing response at three days was limited to formation of granulation tissue and a well-organized fibrin clot with entrapped red blood cells and bone fragments.

The lased tibia (fig. 2) demonstrated a crateriform lesion that was approximately two millimeters in diameter and 1.0-1.5 mm in depth. The depth of penetration varied depending upon the thickness of cortical bone at the impact site. A thin surface deposit of carbonaceous black material and coagulated tissue was found covering the most superficial aspect of the wound. Damage induced by the laser appeared to be predominantly thermal with no evidence of gross operative hemorrhage. Superficial steam vacuoles secondary to the thermal injury were a consistent finding.

SEVEN DAYS:

Proliferation of new bone was pronounced in the control tibia with osteoid filling most of the surgical defect (fig. 3). There was no evidence of a persistent inflammatory infiltrate.

Proliferation of new bone was minimal in the lased tibia (fig. 4). When observed, the deposition of osteoid was always endosteal with only rare extension to the periosteal surface. A foreign body type of inflammatory response consisting of macrophages and giant cells with mild fibrosis was noted in the region of the carbonized material.

FOURTEEN DAYS:

The healing response to the bur wound consisted of numerous trabeculae of immature bone which completely filled the surgical defect (fig. 5).

The lased tibia displayed a predominantly endosteal proliferation of new bone which did not extend into the surgical wound. Instead, it formed a bridge of bone beneath the defect which separated it from the medullary space (fig. 6). The continued presence of carbonized debris on the superficial aspect of the laser wound resulted in a persistent foreign body response with multiple giant cells (fig. 7).

TWENTY-EIGHT DAYS:

All the animals demonstrated either complete or nearly complete healing in the control tibia. Four rats revealed no evidence of a residual defect on either gross or microscopic examination. These animals were interpreted as demonstrating complete healing. In the remaining animals, the original surgical site was located with difficulty. When evaluated histologically, these sites consisted of a solid plug of mineralized bone (fig 8).

The surgical site on the lased tibia was circumscribed with persistent black carbonized debris covering the surface. Occasional specimens were noted to have a fibrous tissue filling the depression to a variable degree. Histologic examination revealed that healing of the superficial aspect of the wound was retarded due to the enduring carbonized tissue elements (fig. 9). Much of the debris was encapsulated by fibrous connective tissue and under attack by foreign body giant cells. The endosteal bridge of bone formed a well-mineralized internal callus.

DISCUSSION

Healing of the bur wound progressed in an orderly fashion with complete or nearly complete healing evident by the twenty-eighth postoperative day. In contrast, the laser wound exhibited retarded healing from the seventh to the twenty-eighth day with gross and microscopic evidence of a persistent defect on the final experimental day.

The failure of the lased tibiae to progress to complete healing is attributed to the continuous presence of carbonized tissue debris from the laser impact. It is reasonable to assume that careful debridement of the laser osteotomy holes would result in a more favorable healing response. Further investigation is indicated to explore this assumption.

The tissue reaction to the carbonized debris was observed to be a low grade, foreign body type response. Other than this finding, there was neither gross nor histologic evidence of persistent detrimental laser effects upon bone. The deposition of new bone in the healing laser wound was derived exclusively from endosteal proliferation. This was in contrast to the controls which demonstrated both endosteal and periosteal proliferation of new bone to fill the surgical defect. However, by the final postoperative day the endosteal deposition of new bone had bridged the deep aspect of the laser wound. The result was an operative site that had functionally healed despite the persistent superficial defect.

The carbon dioxide laser is a potentially valuable tool for bone surgery in selected cases. This study has demonstrated that a retarded rate of healing may be expected when the laser is used without careful debridement of the operative field following impact. Gross and microscopic examination revealed no additional detrimental effects upon bone. Further investigation is necessary to determine if production of larger surgical defects, increased power levels, and sustained exposure will result in a similar response.

SUMMARY

A small defect which penetrated the cortex was produced in the tibiae of forty white rats by a carbon dioxide surgical laser. The tissue response was examined histologically at three, seven, fourteen, and twenty-eight days following the surgical procedure. Healing was compared to defects produced by a number four round surgical bur in the contralateral tibiae. The lased tibiae demonstrated a retarded rate of healing and a persistent superficial defect at the impact site. This retarded healing was most likely due to a surface deposit of carbonized tissue elements produced by the thermal effects of the laser. Presence of carbonized debris stimulated a low-grade, foreign body response. No additional detrimental effects were observed to be induced by the carbon dioxide laser.

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ILLUSTRATIONS

Fig. 1. Bur wound on the third postoperative day demonstrating granulation tissue and a fibrin clot with entrapped red blood cells and fragments of bone. (Hematoxylin and eosin, x 60.)

Fig. 2. Laser wound on the third postoperative day. A surface deposit of carbonized tissue elements is observed. (Hematoxylin and eosin, x 40.)

Fig. 3. Bur wound on the seventh postoperative day. Osteoid formation fills the entire surgical defect. (Hematoxylin and eosin, x 60.)

Fig. 4. Laser wound on the seventh postoperative day. Persistent carbonized debris and endosteal proliferation of new bone can be noted. Hematoxylin and eosin, x 100.)

Fig. 5. Bur wound on the fourteenth postoperative day. The defect is filled with trabeculae of immature bone (Hematoxylin and eosin, x 60.)

Fig. 6. Laser wound on the fourteenth postoperative day demonstrating surface carbonized debris and an endosteal bridge of bone. (Hematoxylin and eosin, x 100.)

Fig. 7. Laser wound on the fourteenth postoperative day. Giant cells with engulfed carbonized debris are apparent. (Hematoxylin and eosin, x 400.)

Fig. 8. Bur wound on the twenty-eighth postoperative day demonstrating a solid plug of mature mineralized bone. (Hematoxylin and eosin, x 100.)

Fig. 9. Laser wound on the twenty-eighth postoperative day. Carbonized debris encapsulated by fibrous connective tissue is observed. (hematoxylin and eosin, x 60.)