Acta orthop. Scandinav. 42, 465–481, 1971

Department of Orthopaedics, University of Nijmegen,
Nijmegen, The Netherlands.

THE INFLUENCE OF ACRYLIC CEMENT

An Experimental Study

T. J. J. H. Slooff

Accepted 19.ix.71

The purpose of this study was to establish the influence of acrylic cement on the bone tissue at different intervals of time. Therefore the acrylic cement was introduced into the medullary cavity. The reaction provoked by this cement was studied radiologically and histologically.

MATERIAL AND METHODS

The experiment involved six male and six female adult dogs of different breeds (Table 1). Prior to the operation the dogs were in good condition and showed no abnormalities. They were fed a normal diet. The body weights ranged from 9.5 to 28.7 kg.

In order to study the influence of acrylic cement at different points of time, the dogs were sacrificed after different intervals. Details on date of operation, postoperative survival, date of postmortem and date of intravenous tetracycline injection are presented in Table 1.

Acrylic Cement

The cement used was the polymethyl-methacrylate "Palakos R" (Kulzer & Co., Hamburg, West Germany) in the normal commercial packing of 40 g polymer and 20 ml monomer. For use, the two components were mixed until a paste was obtained which no longer adhered to the rubber glove. Once this pasty stage was reached, the cement was injected into the femoral medullary cavity down to a far distal level by means of a metal syringe of special design.

Technique

The operation was performed under general anaesthesia, introduced by an intravenous injection of 0.5 mg atropine followed by thiopental sodium (Pentothal) at a dosage of 15 mg/kg body weight.

After intratracheal intubation the anaesthesia was maintained with a mixture of oxygen, nitrous oxide and halothane.

Table 1.

Dog no.	Weight in kg	Sex	Date of operation	Survival in days	Date of sacrifice	Date of tetracycline injection (25 mg/kg body weight)	
950	21	♂	10–3–69	10	21–3–69	20–3–69	
1016	19.4	♂	11–4–69	34	16–5–69	15–5–69	
1011	28.7	♀	11–4–69	40	22–5–69	21–5–69	
1000	17.3	♂	28–3–69	59	27–5–69		
996	22.5	♀	28–3–69	61	29–5–69	28–5–69	
939	16.2	♀	12–3–69	88	9–6–69	5–6–69 9–6–69	½ week
943	18.3	♂	17–3–69	91	17–6–69	10–6–69 17–6–69	1 week
934	15.1	♀	2–4–69	91	3–7–69	2–6–69 2–7–69	4 weeks
949	20.8	♂	17–3–69	98	24–6–69	10–6–69 23–6–69	2 weeks
974	14.7	♀	24–3–69	104	7–7–69	10–6–69 6–7–69	4 weeks
962	19	♂	19–3–69	105	3–7–69	10–6–69 2–7–69	3 weeks
971	9.5	♀	2–4–69	109	22–7–69	2–6–69 21–7–69	7 weeks

The operation was performed on the right femur in all cases. X-rays of both femurs were obtained before and after the operation.

The right gluteal region was shaved, washed and painted with iodine and then draped with sterile towels, leaving the area over the right greater trochanter uncovered.

In the skin over the greater trochanter an incision of 4 cm was made parallel to the length of the bone; this was followed by direct dissection down to the bone. A subtrochanteric defect was made in the cortical bone by chiselling out a flap of 2 × 1 cm. The medullary cavity was not drained by suction and curetted; the structure of the spongiosa in the trochanteric region was left intact.

A teflon tube of suitable diameter was then introduced through the defect after being connected to the cylinder of a metal syringe. The tube was passed down as far distally as possible.

After preparing the acrylic cement and connecting the metal syringe, the cement was packed into the medullary cavity. By gradual withdrawal of syringe and tube while the screw-spindle was turning, the entire intramedullary cavity was filled. After this procedure the bone flap was restored to its original position and the wound was closed in layers.

All surgical wounds healed *per primam*. One week after the operation all dogs showed a normal pattern of locomotion.

During the interval between operation and death, no complications were observed except in dog no. 1000, which died from unknown causes two months after the operation. Histological examination of this dog's femur disclosed osteomyelitis. This dog was excluded from this study.

Preparation of Dogs for Histological Examination

All dogs were given tetracycline intravenously (Table 1) so as to ensure that an impression of the degree of ossification and osteogenesis could be gained at a given time from the calcification fronts demarcated by the tetracycline. The tetracycline used was oxytetracycline hydrochloride (Pfizer). The dosage was 25 mg/kg body weight.

After sacrificing the dog by intravenous injection of an overdose of pentobarbital sodium (Nembutal: 1–3 ml), the two femurs were dissected out.

After obtaining X-rays of both femurs, the femoral diaphyses were cut into transverse discs of about 1 cm thickness, which were numbered from the proximal to the distal end. Every other disc was fixed in buffered formalin, the remaining discs being fixed in absolute ethyl alcohol.

The formalin-fixed discs were decalcified in a solution of ethylene-diamine-tetra-acetic acid and embedded in paraffin, whereupon sections of 7 μ thickness were cut and stained with haematoxylin-eosin.

The alcohol-fixed discs were embedded in methyl-methacrylate plastic, whereupon sections of 80 μ thickness were cut out. These sections were not stained.

The dogs numbered 939, 943, 934, 949, 974, 962 and 971 were given two injections of tetracycline, the interval between the two injections being one-half, one, four, two, four, three and seven weeks, respectively. This made it possible to gain a good impression of the degree of osteogenesis during the interval between the injections.

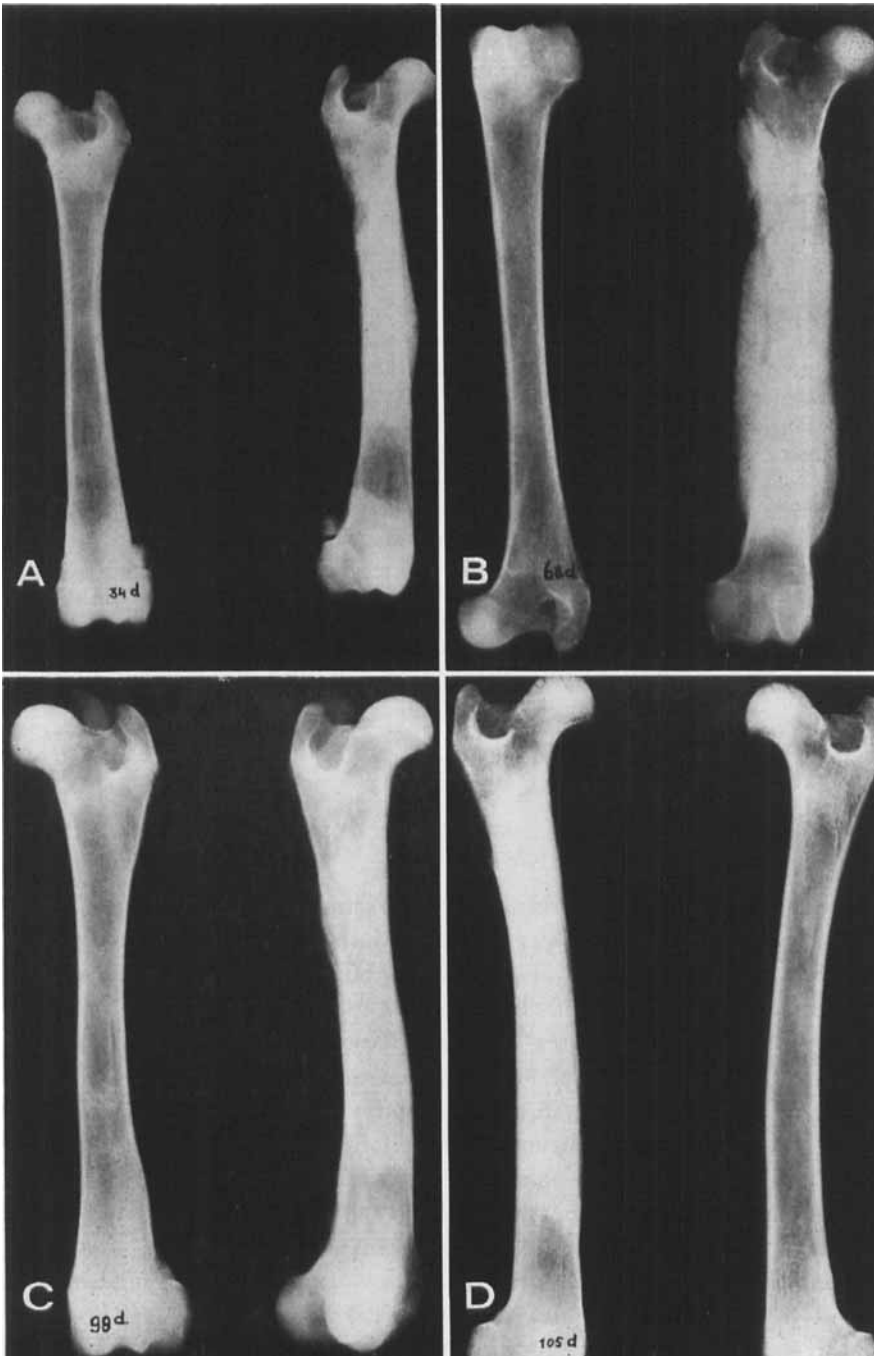
RESULTS

Radiological Findings

X-rays of all treated femurs were obtained immediately after the operation. All these X-rays showed that the cement filled three-quarters of the medullary cavity; contact with the endosteal wall of the cortical bone was good throughout the length of the cavity.

The first visible changes were observed after 34 days in dog no. 1016: irregularly bounded subperiosteal bone apposition, which was maximal halfway the length of the diaphysis and gradually diminished in proximal and distal direction. No distinct structure was recognizable in this appositional bone. The apposition layer was 5 mm thick. As compared with the control femur, the cortical bone structure did not have its normal structure (Figure 1 A).

Sixty-one days after the operation the subperiosteal apposition was found to have substantially increased throughout the length of the diaphysis. The thickness halfway the diaphysis was 10 mm, diminish-


A
34 d
B
68 d
C
98 d
D
105 d

ing in proximal and distal direction. The cortical bone structure was vague, with areas of rarefaction (Figure 1 B).

The features observed after 88 and after 91 days were identical to those found after 61 days, but circular bone apposition was unmistakably decreased. Maximal thickness halfway the diaphysis was 4 mm.

After 98 days (dog no. 949) only moderate subperiosteal bone apposition remained, with bone densifications in longitudinal direction. The wall of cortical bone was broadened in comparison with the control femur, and showed rarefactions alternating with densified structures (Figure 1 C).

After 105 and 109 days, X-rays showed a slight periosteal bone reaction with a maximum halfway the diaphysis. The wall of cortical bone showed a less dense structure (Figure 1 D). All radiographs showed that contact between acrylic cement and endosteal wall of cortical bone had been maintained.

Macroscopic Findings

Macroscopic examination of the dissected femurs revealed that the radiologically established periosteal bone apposition was clearly visible (Figures 2 A, B). This tissue proved to be of hard consistency. The features of the periosteal tissue were normal in all cases.

In two cases, cement distributed in the muscle-tissue was encapsulated by connective tissue. The original site of the surgical femur defect could be traced only with difficulty; it was concealed from view by periosteal bone apposition.

Once the treated femur had been cut into transverse discs of 1 cm

---

Figure 1 A. No. 1016: Röntgenogram of left control femur and right treated femur. Note the subperiosteal apposition of bone in the mid-portion of the right femur shaft.

Figure 1 B. No. 996: Röntgenogram of left control and right treated femur 61 days after operation. The subperiosteal apposition is more profuse and extensive.

Figure 1 C. No. 949: Röntgenogram of left control and right treated femur 98 days after operation. The bone apposition is decreased and the cortical wall shows rarefactions alternating with dense structures.

Figure 1 D. No. 962: Röntgenogram of control femur at the right and treated femur (left), 105 days after operation. Note the slight subperiosteal bone apposition. The structure of the cortical wall shows a spongeous character.

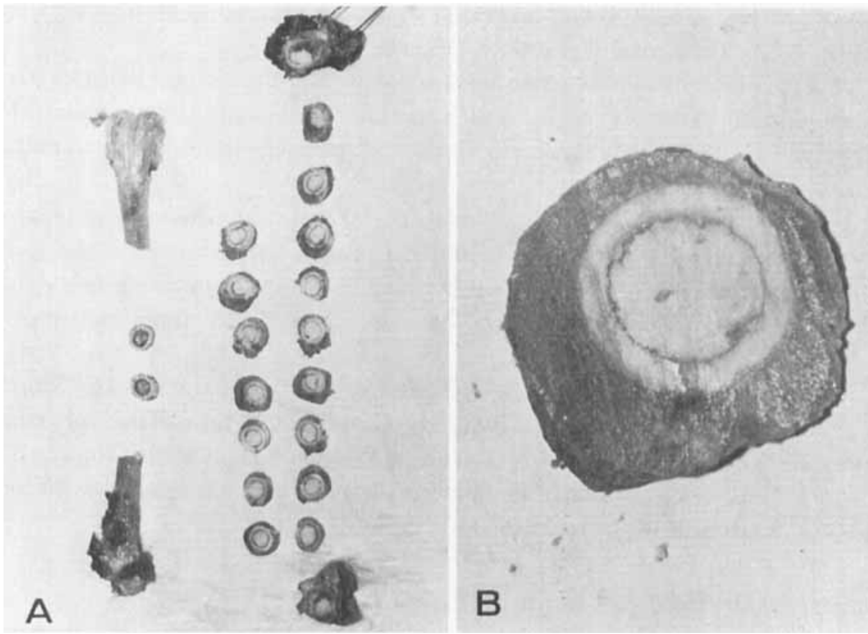


Figure 2 A. No. 1011: Macroscopic picture of a treated femur (ri) 40 days after operation. The maximum of the subperiosteal bone formation is situated in the mid portion of the femur shaft. The control femur at the left. Figure 2 B shows the enlargement of a transverse bone section. The acrylic cement lies in the entre. The callus formation lies around the pre-existent corticalis.

thickness, the cement was found to be very firmly adherent to the endosteal wall of the corticalis.

DISCUSSION

The most conspicuous feature of all treated femurs was the increase in diameter resulting from circular subperiosteal bone apposition. In all cases this apposition extended throughout the length of the diaphysis. In this experiment it was first observed after 34 days, reached a maximum after 61 days, and gradually diminished to a minimum after 105 days.

It is considered plausible that the first radiological changes become visible between the 10th and the 34th postoperative day.

The same proliferative appositional bone formation has been described in the experiments of Trueta & Cavadias (1955), Rietz (1968), and Danckwardt-Lilliesträm (1969).

It is of importance to note that the pre-existent cortical bone shows radiological structural changes. After 34 days the cortical bone shows some blurring and even partial effacement, whereupon a cortical bone structure gradually becomes visible, in which local rarefactions are seen. Finally the corticalis has a spongeous structure.

In the course of the experiment the impression was gained that the subperiosteal apposition primarily occurs halfway the length of the diaphysis; the proximal and distal portions of the femur are not involved in the process until later. The intensity of the periosteal reaction, too, was always found to be higher halfway the diaphysis than in the proximal and distal portions.

No radiological changes were seen in the acrylic cement in the course of the experiment. It retained its firm contact with the endosteal site of the corticalis. This mechanical bonding between acrylic cement and bone has been described in the experiments of Henrichsen, Jansen & Krogh Poulsen (1951).

CONCLUSIONS

After complete filling of the femoral medullary cavity with acrylic cement, macroscopic and radiological osseous changes were observed in dogs.

The diameter of the femur increased as a result of circular subperiosteal apposition—a reaction which attains its maximum about 60 days after the operation and then gradually diminishes. This reaction shows a maximum both in time and in place. In all treated femurs the maximum reaction was localized halfway the length of the diaphysis.

In addition to osteogenesis there were structural changes in the appositional bone as well as in the pre-existent cortical bone.

No radiological changes were observed in the acrylic cement, which retained its contact with the endosteal wall of cortical bone throughout the experiment.

HISTOLOGICAL STUDY

Bone discs of about 1 cm thickness, marked A, C, E, etc., were decalcified, embedded in paraffin and cut into sections. The discs marked B, D, F, etc. were embedded in plastic and cut into sections. Control sections were obtained from the untreated (left) femur. The following are the principal findings obtained by histological examination of these series of sections.

No. 950 (10 Days After Operation)

An incipient subperiosteal bone apposition is present which, in view of the comparative levels of the sections, has its maximum halfway the length of the diaphysis. More proximal and distal levels show hardly any periosteal reaction.

Halfway the length of the diaphysis there is necrosis of the endosteal aspect of the cortical bone, manifested by absence of tissue structures in the haversian canals. The osteocyte nuclei are still present.

The plastic-embedded section shows occasional tetracycline markings on the periosteal side of the cortical bone around the marrow canals; this finding is suggestive of local osteogenesis. The endosteal side is covered by some granulation tissue without foreign-body reaction.

No. 1016 (34 Days After Operation)

Halfway the length of the diaphysis the subperiosteal bone apposition—already existing after 11 days—has become more extensive. A sharp demarcation is seen between the subperiosteal apposition and the pre-existent cortical bone (Figure 3). The necrosis of the cortical bone (endosteal side) is even more apparent in that the majority of the osteocytes have disappeared from the lacunae.

The tetracycline marking shows that the ossification around the subperiosteal canals—already noted after 11 days—is increasing. In this series of sections, too, the intensity of the processes is maximal

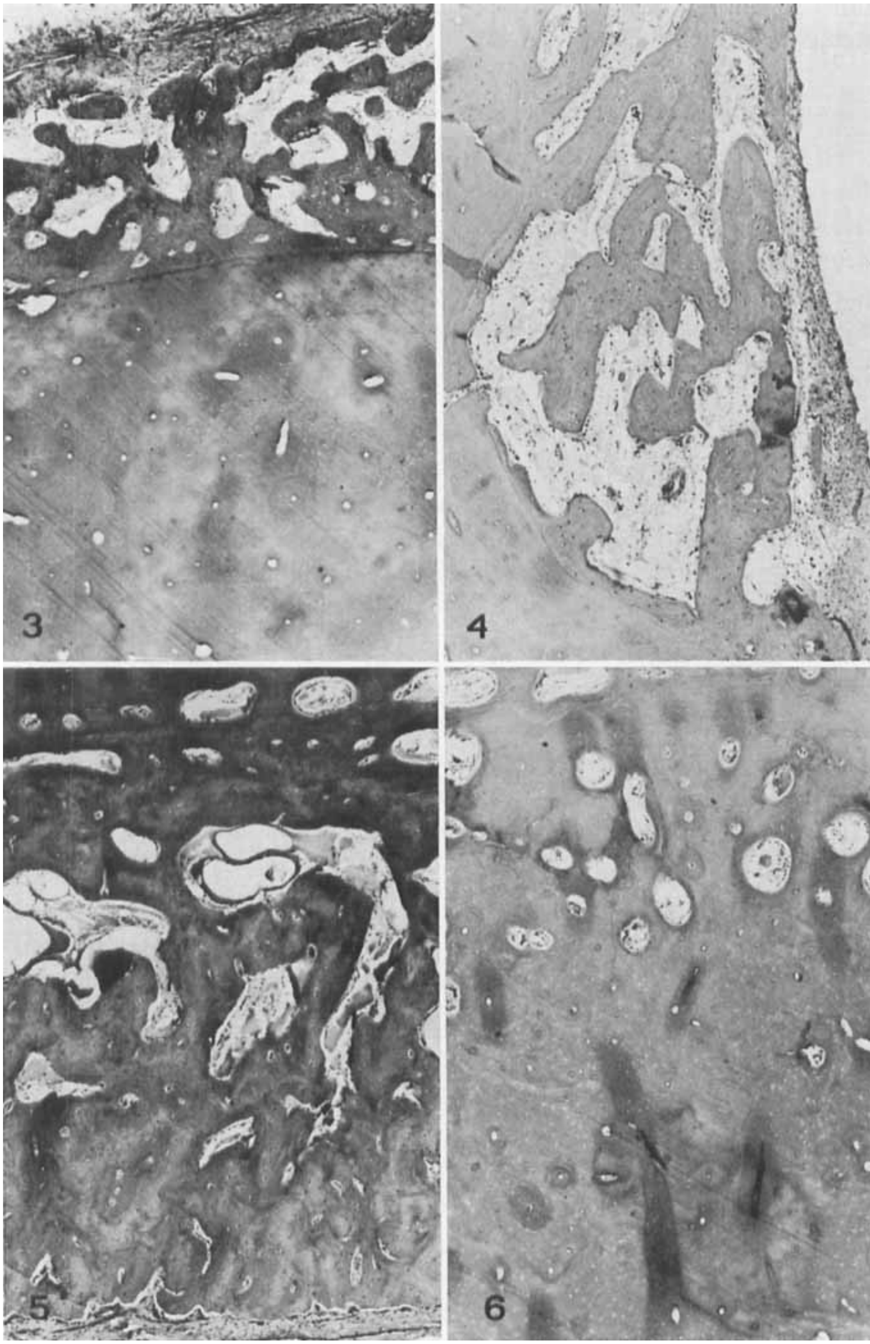
---

Figure 3 (40 ×). No. 1016: Histological appearance of a section of a treated femur 34 days after operation. A sharp demarcation is seen between the subperiosteal callus formation and the necrotic area in the corticalis.

Figure 4 (40 ×). No. 1011: Histological appearance of an area endostally situated 40 days after operation. Adjacent to necrotic areas in the corticalis islets of active osteogenesis are seen.

Figure 5 (40 ×). No. 996: In the subperiosteal layer signs of maturation are observed 61 days after operation. The lacunes are invaded by newly formed cells.

Figure 6 (40 ×). No. 996: The osteoblast activity is directed from subperiostally to endostally.


3
4
5
6

halfway the length of the diaphysis and diminishes in proximal and distal direction.

No. 1011 (40 Days After Operation)

These sections show the same feature as those of no. 1016, but on the endosteal side of the cortical bone virtually all osteocytes have disappeared, indicating the spread of necrosis. Adjacent to the medullary cavity, a layer of delicate collagenous tissue without foreign-body giant cells is forming on the endosteal surface of the cortical bone. Beneath this layer endosteal osteogenesis is taking place at the sites of rarefaction in the cortical bone (Figure 4).

No. 996 (61 Days After Operation)

The already described periosteal bone apposition is showing signs of maturation. Unmistakable osteoblast activity is observed in the subperiosteal cortical regions. This activity spreads in endosteal direction around revascularized marrow canals (Figures 5 and 6).

No. 939 (88 Days After Operation)

Increasing maturation of sub-periosteally formed bone and ossification in subperiosteal areas of the cortical bone. At the boundary between the endosteal cortical bone and the space which has accommodated the acrylic cement, a layer of connective tissue has formed in which foreign-body cells are observed (Figures 7 and 8).

No. 943 (91 Days After Operation)

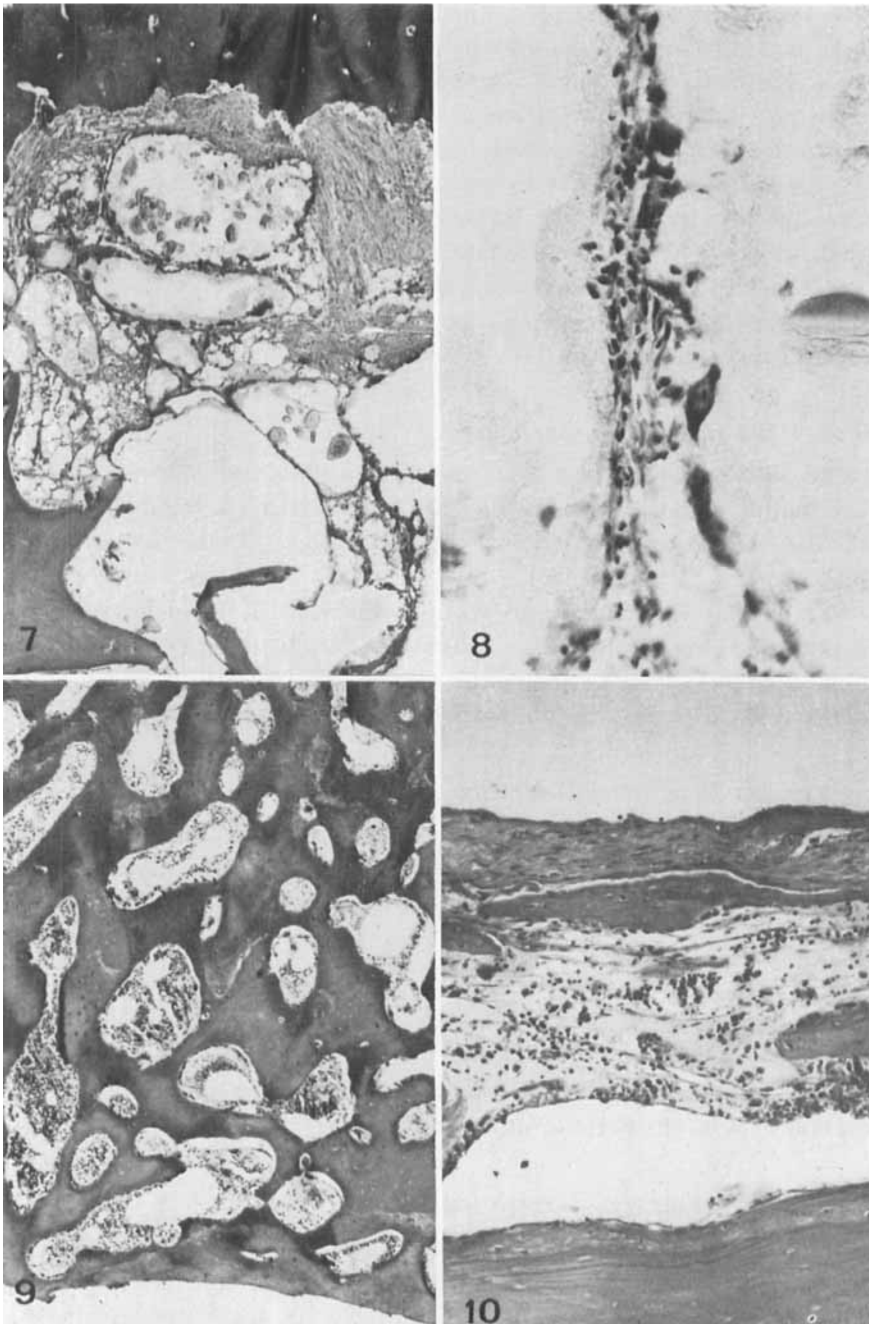
Subperiosteally, the apposition bone locally assumes the features of cortical bone tissue. The thickness of the apposition bone is evidently less than in the sections of No. 939.

Figure 7 (40 ×). No. 939: Foreign-body giant cells around spaces which were filled with acrylic cement 88 days after operation.

Figure 8. No. 939: 250 × enlargement of foreign-body giant cells.

Figure 9 (40 ×). No. 934: Histological appearance of dilated haversion canals in the pre-existent corticalis 91 days after operation.

Figure 10 (125 ×). No. 962: Enlargement of a spongeous area. Note the connective tissue membrane.


7
8
9
10

Osteogenesis is taking place throughout large subperiosteal cortical areas and also at various sites in the endosteal cortical bone. Double tetracycline markings are observed around the canals in the subperiosteal layer; in the endosteal layer only a single band encircles the canals. The distance between the two bands (subperiosteally) provides a measure of the amount of bone newly formed during the intervals between the two tetracycline injections. In this case the interval was one week (see Table 1).

The fact that only one tetracycline band is visible in the endosteal layer indicates that osteogenesis in this region did not start until after the first tetracycline injection.

No. 934 (91 Days After Operation)

The features are identical to those in no. 943, but it is conspicuous that the haversian canals in the pre-existent cortical regions throughout the femur are dilated: spongy alteration of the cortical bone (Figure 9).

Throughout the transverse section the cortical bone shows tetracycline marking around the haversian canals. Particularly on the subperiosteal side there are double bands, the distance between which corresponds with the interval between the two injections.

No. 949 (98 Days After Operation)

As compared with no. 934, more advanced maturation of subperiosteal bone apposition and spongy alteration of the cortical bone. Osteogenesis extends into the endosteal areas.

No. 974 (104 Days After Operation)

A striking feature of these sections is the presence of double tetracycline bands around the marrow canals, extending into the endosteum. The distance between these bands corresponds with a time interval of 4 weeks between injections.

No. 962 (105 Days After Operation)

The features are identical to those of the sections of no. 974. The periosteal bone apposition is of limited thickness and shows evident maturation. Matured bone is present also at some endosteal sites. Necrotic marrow canals are no longer visible (Figure 10).

No. 971 (109 Days After Operation)

The maturation of endosteal osteogenesis is further advanced, as is the periosteal bone apposition. The cortical bone shows a spongiosa structure; dilatation of the medullary vessels. The distance between the tetracycline bands in these sections is considerable, corresponding to an interval of 7 weeks between injections.

DISCUSSION

The study of the histological sections disclosed the following important features: subperiosteal bone apposition, partial necrosis of the cortical bone, a foreign-body reaction and gradual disappearance of the cortical necrosis.

The subperiosteal bone apposition can already be observed after 10 days, and the same applies to the cortical necrosis. The latter remains confined to the innermost two-thirds of the corticalis.

Regeneration of the corticalis occurs from the periosteum and gradually extends throughout the cortical wall in the course of 109 days. These regenerative processes from periosteal to endosteal regions are first observed after 61 days, after which remodelling of the entire cortical bone takes place.

The above-mentioned reactions involve the entire length of the diaphysis.

Similar findings have been reported by Trueta & Cavadias (1955, 1964), Rietz (1968) and Danckwardt-Lilliesträm (1969). Trueta & Cavadias (1955) ligated the femoral nutrient arteries in a series of dogs, and introduced a Küntscher nail into the medullary cavity in the next series. Both procedures led to reversible necrosis of the inner two-thirds of the cortical wall. They also describe the subperiosteal bone reaction; they believe that lesions of the femoral nutrient arteries cause the periosteal vessels to take over the vascularization of the bone, which leads to subperiosteal osteogenesis.

Rietz (1968) submitted dog femurs to segmental resection and restored continuity by means of a cemented metal prosthesis; he observed periosteal bone apposition both in the group of the stable and in that of the unstable prostheses. In the latter group, however, the degree of osteogenesis was significantly higher. He mentions that periosteal activity diminishes after some time, and that the cortical bone is remodelled in the course of the experiment. Between the acrylic cement and the endosteal aspect of the cortical bone, Rietz demonstrated islets of osteogenesis as well as a connective tissue membrane of varying thickness, containing foreign-body giant cells.

Danckwardt-Lillieström (1969) reported in a detailed study on the periosteal, cortical and medullary reaction following lesions of the nutrient arteries caused by curettage, reaming and suction drainage of the femoral medullary cavity in dogs and rabbits. He concluded that, after total destruction of the nutrient arteries, the blood supply to the entire cortical bone can be maintained by the periosteal vessels. The latter responded to the operative procedure by dilatation and coiling. He observed that the ischaemic-necrotic cortical regions are revascularized from the hyperactive periosteal vessels, and that the subperiosteal osteogenetic activity is increased.

With a view to these publications on comparable experiments, we believe that the findings we obtained can be ascribed to lesions of the nutrient arteries caused by the operative procedure, the passage of a teflon tube and subsequent packing of the medullary cavity with acrylic cement. In addition, we regard it as likely that this procedure leads to an increase in intramedullary pressure, which may give rise to the formation of a so-called medullohaematoma (Zuckman 1968) and massive fat embolism (Danckwardt-Lillieström 1969 a, 1969 b).

In one of the experiments carried out by Danckwardt-Lillieström, embolus formation and increase of pressure were reduced by suction drainage of the medullary cavity before and during the operative procedure. The avascular region in the cortical bone was thus markedly reduced.

We confirmed this observation in a series in which the medullary cavity was drained by suction and only partly packed with cement, reducing the increase in pressure and the damage to the nutrient arteries: subperiosteal bone apposition did not occur in this series (in press).

Apart from this mechanical factor, the thermal reaction must be mentioned as a second cause of the cortical necrosis. The polymerization heat of the acrylic cement used is mainly dependent on the amount of cement introduced (Ohnsorge-Kroesen 1969, Ohnsorge-Goebel 1969, Charnley 1970). We did not measure the temperature but believe that it must have been high in view of the large amount of cement introduced (10–12 ml).

The exact contribution of each of the two causes to the bone reactions described has not been established. We did demonstrate, however, that an unmistakable tendency toward restoration of the ischaemic-necrotic cortical region occurred after some time, the process developing from the periosteal to the endosteal aspect.

We were unable to demonstrate a permanent sharp line of demarcation between the necrotic cortical bone and the vital subperiosteal cortical bone. We observed that the regenerative process—the reconstruction of the cortical bone—invaded the endosteal cortical bone from the periosteal aspect after about 60 days.

With advancing regeneration and revascularization, the subperiosteal apposition diminishes and the pre-existent cortical bone assumes a spongiosa structure (after 91 days). After 109 days, most of the ischaemic-necrotic cortical bone is regenerated. At that time restoration is nearly complete.

After a few weeks, a delicate collagenous connective tissue layer is formed between cement and endosteal cortical bone in all sections described; this layer closely followed the configuration of the bone surface. It seems probable that the space between bone and cement is filled up by this connective tissue. This means that it is not of the same thickness throughout but shows local thickening, defects in the cortical bone being filled by endosteal osteogenesis (Schenk-Willenegger-Bandi 1966, Rietz 1968, Boitzy 1969, Charnley 1970). Foreign-body giant cells were found in this connective tissue layer after 88 days.

This finding is in agreement with data from the literature (Henrichsen et al. 1951, Debrunner 1953, Müller 1962, Huggler 1968, Willert-Schreiber 1969, Charnley 1970). No necrosis or inflammatory reactions were observed near these giant cells.

Finally it should be pointed out that new bone—tetracycline-marked osteons and trabeculae—is forming itself in the immediate vicinity of the acrylic cement.

CONCLUSIONS

Packing of the entire femoral medullary cavity with acrylic cement in dogs led to partial necrosis of cortical bone, associated with subperiosteal bone apposition. Both reactions were reversible, and their principal cause was probably damage to the nutrient arteries. In view of the large amount of cement introduced, thermal damage may also have been involved.

The ischaemic-necrotic cortical bone was gradually regenerated by revascularization from the subperiosteal aspect; this process was first observed in the series of sections after 61 days, and was extended to the endosteum of the corticalis after 109 days.

On the endosteal side of the cortical bone a layer of connective tissue of varying thickness developed in which foreign-body giant cells were observed.

No inflammatory reactions were seen in the vicinity of the acrylic cement. It can be stated that, within the time limits of this experiment, we observed no permanent harmful influence of the acrylic cement and the operative procedure on the bone tissue.

SUMMARY

This paper describes an animal experiment made in order to study the influence of acrylic cement on the bone tissue at different intervals of time introduced into the medullary cavity.

The most conspicuous reaction to complete cementing of the femoral medullary cavity was radiological evidence showing a circular increase in bone diameter due to apposition of newly formed bone in which structural changes occurred in the course of 10 till 109 days after operation.

Macroscopic examination of the various bone discs showed that the cement remained very firmly attached to the inferior cortical wall.

Histological examination disclosed transient partial necrosis in the pre-existent corticalis and subperiosteal bone apposition. Where the cement had touched the inferior cortical wall, a connective tissue membrane of various thickness had been formed. Foreign-body giant cells were formed in this membrane. No inflammatory reactions were observed. After some time there was regeneration of the ischaemic-necrotic areas in the corticalis, a process developing from the periosteum to the endosteum.

It must be considered probable that the bone reactions observed were caused by damage to the nutrient arteries.

REFERENCES

Boitzy, A. (1969) A propos de l'ostéosynthèse des fractures pertrochanteriennes avec utilisation de méthacrylate de méthyle. *Ther. Umsch.* **26**, 172–177.

Charnley, J. (1970) *Acrylic cement in orthopaedic surgery.* E. S. Livingstone, London.

Danckwardt-Lilliestrõm, G. (1969) Reaming of the medullary cavity and its effect on diafysal bone. *Acta orthop. s and.*, Suppl. 128.

Danckwardt-Lilliestrõm, G. (1969) Marrow embolism as a cause of circulation block after surgery to the medullary cavity. *Europ. Surg. Res.* **1–3**, 174.

Debrunner, H. U. (1953) Die Verträglichkeit von Polymethylacrylat. *Z. Orthop.* **83**, 557–581.

Henrichsen, E., Jansen, K. & Krogh-Poulsen, W. (1951) Experimental investigation of the tissue reaction to acrylic plastics. *Acta orthop. scand.* **21**, 141–146.

Huggler, A. H. (1948) *Die Alloarthroplastik des Hüftgelenkes.* Georg Thieme Verlag, Stuttgart.

Müller, M. E. (1962) Die Verwendung von Kunstharzen in der Knochen Chirurgie. *Arch. Orthop. Unfall-Chir.* **54**, 513–522.

Ohnsorge, J. & Goebel, G. (1969) Oberflächentemperaturen des abhärtenden Knochenzementes Palacos beim Verankern von Metallendoprothesen in Oberschenkelmarkraum. *Arch. Orthop. Unfall-Chir.* **67**, 89–100.

Ohnsorge, J. & Kroesen, A. (1969) Thermoelektrische Temperaturmessungen des abhärtenden Knochenzementes Palacos. *Z. Orthop.* **106**, 476–482.

Rietz, K. A. (1968) Polymer osteosynthesis III. *Acta chir. scand.,* Suppl. 388.

Trueta, J. & Cavadias, A. X. (1955) Vascular changes caused by the Küntscher type of nailing. *J. Bone Jt Surg.* **37**-B, 492–505.

Trueta, J. & Harrison, M. H. M. (1953) The normal vascular anatomy of the femoral head in adult man. *J. Bone Jt Surg.* **35**-B, 442–261.

Willenegger, H., Schenk, R. & Bandi, W. (1966) Die Anwendung von Leimsubstanzen in der Knochenchirurgie. *Melsunger med. Mitt.* **100**, 2487–2493.

Willert, N. G. & Schreiber, A. (1966) Unterschiedliche Reaktionen von Knochen- und Weichteillager auf Autopolymerisierende Kunststoff-Implantaten. *Z. Orthop.* **106**, 231–252.

Zucman, J., Maurer, P., Berbesson, C. & Barbot, J. (1968) Etude expérimentale de l'action ostéogénique des greffes de périoste, des greffes de moelle osseuse et de l'alesage centro-médullaire. *Rev. Chir. orthop.* **54**, 15–36.