CORROSION OF ORTHOPAEDIC IMPLANTS

SMITH-PETERSEN TYPE HIP NAILS

BY

JOHN T. SCALES, M.R.C.S., L.R.C.P.
Senior Lecturer, Department of Biomechanics and Surgical Materials, Institute of Orthopaedics (University of London); Consultant in Orthopaedic Prosthetics, Royal National Orthopaedic Hospital, Stanmore, Middlesex

G. D. WINTER, B.Sc.
Research Assistant, Department of Biomechanics and Surgical Materials, Institute of Orthopaedics (University of London)

AND

H. T. SHIRLEY, B.Sc., A.R.C.S.
Brown-Firth Research Laboratories, Sheffield

[WITH SPECIAL PLATE]

Metal implants are used increasingly in orthopaedic treatment, but from time to time complications occur which seem to be attributable to the implant. A programme of work sponsored by the Nuffield Foundation and the Medical Research Council has been undertaken to investigate the applications of materials in orthopaedic surgery. Part of this work has been concerned with the study of implants removed from patients at the Royal National Orthopaedic Hospital and a number of other hospitals, together with the clinical histories, relevant radiographs, and, where available, histological material.

This report is concerned with the incidence of corrosion of 65 Smith-Petersen type hip nails, with four of which a Pidcock pin was also employed.

The term "implant" is used to describe the complete device, while the individual pieces are called components. Each has been studied in the following way: (1) It has been examined for corrosion and other damage by means of the binocular microscope before and after cleaning in nitric acid (specific gravity, 1.20). (2) The type of alloy has been determined by spectrographic analysis. (3) The hardness has been determined by the Vickers "diamond pyramid" method using a 20-kg. load.

Special techniques were used in the examination of some of the components, including non-destructive flaw testing and sectioning. Gross corrosion and deep pitting corrosion can be easily recognized with the naked eye. Less severe degrees of corrosion are seen as dull patches on the otherwise polished surface of the metal, and under the microscope these have a rough, pitted appearance.

TABLE I.—*Alloys Used for Implants*

Group 1: Low-alloy Steels	Group 2: High-alloy Steels		Group 3: Cobalt–Chromium–Molybdenum Alloys
	Martensitic	Chrome–nickel–Austenitic	
13% Cr	17% Cr, 3% Ni	(a) 18% Cr, 8% Ni; (b) 18% Cr, 8% Ni, 0·6% Ti; (c) 18% Cr, 8% Ni, 2·5–3·5% Mo	25/30% Cr, 3/7% Mo, traces of Ni and Mn and Fe, balance Co;

Co = cobalt; Cr = chromium; Mo = molybdenum; Fe = iron; Mn = manganese; Ni = nickel; Ti = titanium

While they may have a superficial resemblance to mechanical damage caused by abrasion, corroded areas can be easily distinguished after some experience. Every component has been checked for corrosion by each of the authors.

The types of alloy from which the components have been made are shown in Table I.

FINDINGS OF INVESTIGATION

Table II shows the incidence of corrosion of the different types of alloy. The 13% Cr alloy implants had suffered severe corrosion, while the high-alloy steels showed less corrosion. The cobalt–chromium–molybdenum implants were not corroded.

TABLE II.—*Incidence of Corrosion*

Type of Alloy	No. of Components Examined	Incidence of Corrosion
13% Cr	9	9
17% Cr, 2% Ni	2	2
18% Cr, 8% Ni	23*	7 (1†)
18% Cr, 8% Ni, 2·5–3·5% Mo	30*	9 (2‡)
Head of nail: 18% Cr, 8% Ni, 2·5–3·5% Mo; Stem of nail: 18% Cr, 8% Ni	1	1
18% Cr, 8% Ni, and up to 0·6% Ti	2	1
64% Co, 30% Cr, 5% Mo	2	0
Total	69	29

* Including two Pidcock pins. † One Pidcock pin corroded. ‡ Two Pidcock pins corroded.

Group 1 Steels

13% Cr Alloy Steel

The dates of insertion of nails made of this alloy are given in Table III. All were inserted after 1940, though it was well known before 1940 that this alloy was not suitable for implants. It is very surprising to find that one nail, A.683, was inserted as recently as May, 1959. No implants made from 13% Cr alloy should now remain in hospital stocks. Since this type of alloy is strongly magnetic, such implants can easily be differentiated from those of austenitic steel.

TABLE III.—13% *Cr Nails*

Implant No.	Date Inserted*	Time in Body
A.46	1946	8 years
A.91	1950	6 ,,
A.175	1944	12 ,,
A.338	1948	8 ,,
A.419	1958	6 weeks
A.460	1940	18 years
A.494	1941	17 ,,
A.606	1942	17 ,,
A.683	1959	14 weeks

* All in United Kingdom.

The nail used in 1958—A.419—was removed after six weeks because the position of the arthrodesis was not satisfactory. There was no extrusion of the nail. The entire surface of the nail was darkly stained and there was a deep corrosion pit in the head (Special Plate, Fig. 1). Nail A.683, inserted in May, 1959, was removed 14 weeks later because of pain associated with penetration of the nail into the acetabulum. There was no extrusion of the nail. The soft tissues over the distal end of the nail were discoloured; there was no evidence of infection, and the wound healed without drainage. Histological examination of tissue from over the head of the nail showed cellular granulation tissue with foreign-body giant cells. There were extensive intracellular and extracellular deposits of iron. The stem of the nail was brightly polished, but there were pits around the rim of the head. In making the nail the head had been fitted to an extension of the stem. The cannula had then been expanded and the junction of the head with the triflanged portion of the stem soldered. This solder had corroded. The internal surface of the cannula was also corroded along its length. This case illustrates clearly the need to review stocks of implants held by hospitals.

Nail A.91, which had not extruded, was removed after six years because of fibrous ankylosis instead of intended arthrodesis. Rarefaction around the nail seen on the radiograph may have been caused by movement. There was slight pitting corrosion at the junction of the head with the stem on the triflanged surface, and a dark discoloration, with slight pitting of the inner surface of the cannula. Nail A.46, which was severely corroded (Special Plate, Fig. 2), had been inserted in 1946 to arthrodese the hip. The patient complained of discomfort in the hip eight years later, and radiographs showed a clear zone of rarefaction around the nail, which had not extruded but appeared to be loose within its track (Special Plate, Fig. 3). The nail was removed. Another severely corroded nail—A.338—also removed after eight years, had been inserted in 1948 to stabilize a slipped upper femoral epiphysis. Radiographs showed a clear zone of rarefaction around the nail, which had not extruded. A pure growth of *Bacillus coliformis* was obtained on culture of material removed from the cannula of the nail. A nail inserted in 1944—A.175—and removed after 12 years because of acute pain, was severely corroded, and a Pidcock pin of 18/8 alloy had also corroded. Radiographs showed that, following avascular necrosis of the femoral head, the nail, which had not extruded, had penetrated into the acetabulum. There was a zone of rarefaction around the nail. Nail A.494, removed after 17 years following avascular necrosis of the femoral head, was severely corroded. It had penetrated the acetabulum. The nail, which had not extruded, was surrounded by a zone of rarefaction. A Pidcock pin of 18/8 alloy was not corroded.

The most severely corroded nail was A.606. In 1942 a patient aged 47, with osteoarthritis of the left hip, had a Smith-Petersen pin arthrodesis supplemented with an ilio-femoral graft. The arthrodesis was successful, and the patient was free from pain for eight years. Then from 1950 to 1952 she complained of pain in her left hip, knee, and lumbar region. A radiograph taken in 1951 (Special Plate, Fig. 4) showed a corrosion pit midway along the nail with a zone of increased density in relation to the pin at this place. The patient was not seen again until 1959, when because of severe pain she attended hospital. A radiograph showed that the pin had corroded through (Special Plate, Fig. 5). There was no extrusion of the nail. At operation considerable soft-tissue reaction around the head of the nail was found. The distal half of the nail was removed, but the proximal portion could not be extracted. When last seen the patient had a recurrence of the severe pain in the hip. The remaining part of the pin will probably have to be removed at a later date.

Another patient had a Smith-Petersen nail—A.460—inserted in 1940 for fracture of the neck of the left femur. The fracture united satisfactorily, and she was completely well until 1955. From then until 1958 she had gradually increasing pain and developed a slight limp, with limitation of abduction and of internal and external rotation. An antero-posterior radiograph (Special Plate, Fig. 6) showed a zone of rarefaction about the stem of the nail, while a lateral radiograph (Special Plate, Fig. 7) showed corrosion of the distal third of the stem. At operation there was no evidence of infection. A McMurray osteotomy was performed and a four-flanged nail and plate inserted, after which the pain was relieved. The nail, which was black in colour, had corrosion pits all over the outer surface and in the wall of the cannula which communicated in the distal third of the nail. The pain in this case may have been due to developing arthritis or to the corrosion. Nevertheless, it was apparent that the corroding nail was causing a tissue reaction.

Rarefaction of bone adjacent to corroding 13% Cr alloy hip nails usually occurs, but sometimes the reaction is one of sclerosis, as occurred with nail A.606. The same radiographic appearances may be due to infection and movement. Infection was proved in one of these cases, but no swabs were taken from the others. In two cases tissue adjacent to the nail and corresponding to the rarefied areas in the radiographs was examined. It was highly collagenous fibrous tissue with iron-containing deposits (Special Plate, Fig. 8).

Group 2 Steels

17% Cr, 2% Ni Alloy Steel (17/2)

This is a martensitic steel, hardenable by heat treatment like the 13% Cr steels, and of intermediate corrosion resistance between these and the austenitic steels. Two nails were made from this type of steel; both were inserted in Great Britain. The head of one nail—A.699—was a push fit on the distal part of the cannula, which had been swaged to lock the head on the stem. It was used in 1959 to treat a fracture of the femur neck in an elderly female who died one month later. The nail had not extruded. There was slight corrosion on the underside of the head at the interface between the head and the flanges. The head of the other pin—A.720—was screwed on the stem. This pin was used in 1947 to treat a fractured neck of femur in an elderly female. It was removed after 13 years because of pain over the head of the nail, which was extruding. The fracture had united. There were corrosion pits on the head of the nail, which had also cracked. The threaded portion of the nail within the head was corroded and the stem of the nail was generally tarnished. This type of alloy should not be used for the manufacture of implants.

18% Cr, 8% Ni Alloy Steel (18/8)

Twenty-one nails made from 18/8 alloy (20 by the same manufacturer) were examined. One of the nails was constructed of three pieces and three of two pieces; the remainder were of one-piece construction. A quantity of dirt was trapped between the separate pieces. One nail was marked with the code letter which normally denotes 18/8/Mo alloy. With the exception

TABLE IV.—*Reasons for Removal of 18/8 Nails*

Principal Reason for Removal	No. of Nails	No. of Nails Corroded
Extrusion	7	2
Routine	4*	—
Nail penetrated into acetabulum	2	—
Pain without any other obvious complication	2	2
Reduction of fracture not satisfactory	1	—
Arthrodesis not attained	1	—
Broken nail	1	1
Avascular necrosis of femoral head	2	—
Infection	1	1
Total	21	6

* Including nail used for arthrodesis of ankle.

of one nail, the date of insertion of which could not be ascertained, all these nails were inserted after 1947 and had been in the body for periods between 18 days and 7 years. They had been used to treat fractures of the femoral neck (13) and slipped femoral epiphysis (3), and for arthrodesis of the hip (4) and ankle (1). Reasons for removal of the nails are given in Table IV.

Six of the 21 nails were corroded. One nail—A.49—was fractured in two places, the appearance of the fractures being consistent with failure by fatigue, though one fracture had been so severely damaged by rubbing that it was not possible to be certain as to the cause. Microscopical examination of the longitudinal section of the nail up to this fracture showed several small transcrystalline cracks parallel to the fracture. An example is shown in Fig. A. The presence of several cracks such as this would suggest that corrosion fatigue was responsible. There was no obvious sign of corrosion on the outer surface of the nail. The cannula contained a considerable amount of oxide or corrosion products, and from an examination of the etched section it appeared that some intercrystalline corrosion had taken place (Fig. B). There was a quantity of carbide out of solution in the inner surface of the wall of the cannula, which suggested that local carburization had occurred during manufacture (Scales *et al.*, 1959). Carburization is an increase in the carbon content of the steel. In this case it arose from diffusion of carbon from a high-carbon-steel mandrel used in the production of the tube from which the triflanged nail had been machined. Steps have now been taken which should overcome this effect. The other five nails showed slight corrosion in various places on the surface of the stem and the head, at the head–stem junction, and in the cannula. Radiographs showed a zone of rarefaction around five of the 21 nails. Neither the radiological appearances nor the "reason for removal" could be correlated with corrosion of the implant. Five of the nails were accompanied by tissue, but in three cases the tissue could not be definitely related to the implant. Histological sections of the other two specimens which were adjacent to corroded implants showed dense fibrous tissue with collections of particulate material which gave a positive staining reaction for iron.

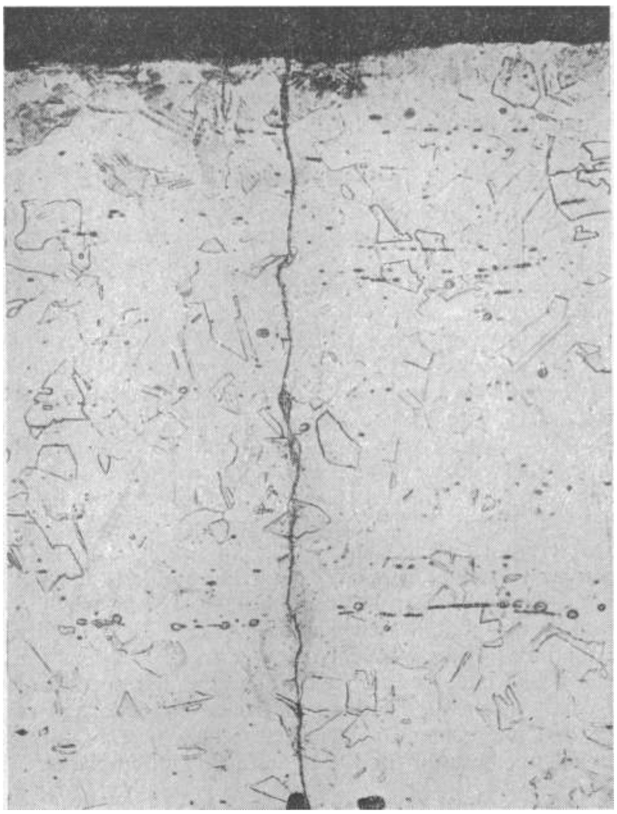

Fig. A.—Nail A.49. Transcrystalline crack parallel to fracture. (×200.)

18% Cr, 8% Ni, 0.6% Ti Alloy Steel (18/8/Ti)

Two nails made from 18/8/Ti alloy were examined. One of these was corroded slightly near the pointed end. Both nails had been used for fixation of fractures of the femoral neck in elderly patients and both were removed because of extrusion of the implant, one after three weeks and the other after five months. There were no changes in the bone visible on the radiographs, nor was there clinical evidence of infection. Both nails were marked with the code letter for 18% Cr, 8% Ni alloy steel.

18% Cr, 8% Ni, 2.5/3.5% Mo Alloy Steel (18/8/Mo)

Twenty-eight nails made from 18/8/Mo alloy by three manufacturers were examined. Eight of the nails, proved by spark spectroscopy to be 18/8/Mo alloy, were marked with a code letter which has been used by one manufacturer for plain 18/8 alloy implants. It is important that implants are marked correctly. Two of the nails had been used with Pidcock pins. Four were

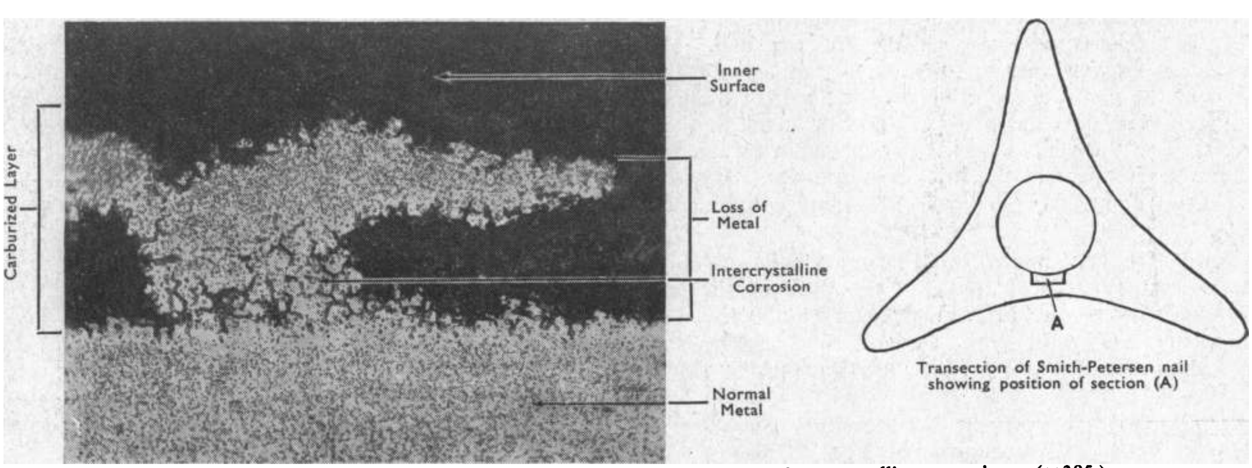

Fig. B.—Nail A.49. Section (A) through wall of cannula showing intercrystalline corrosion. (×385.)

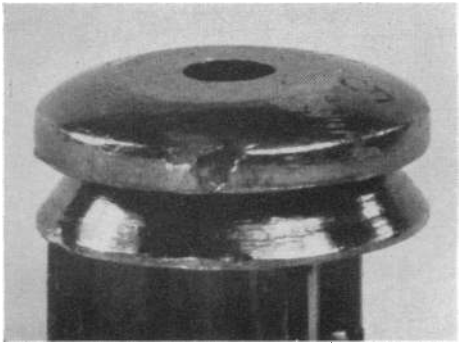

FIG. 1.—Nail A.419. Corrosion pit in head of 13% Cr hip nail removed after six weeks.

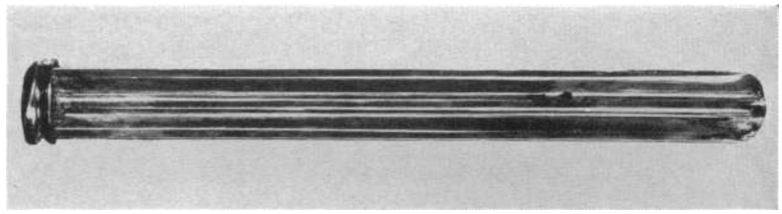

FIG. 2.—Nail A.46. Corroded 13% Cr hip nail removed after eight years

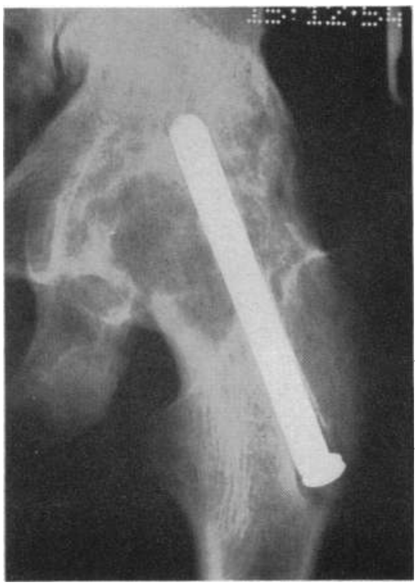

FIG. 3.—Nail A.46. 13% Cr hip nail eight years after operation.

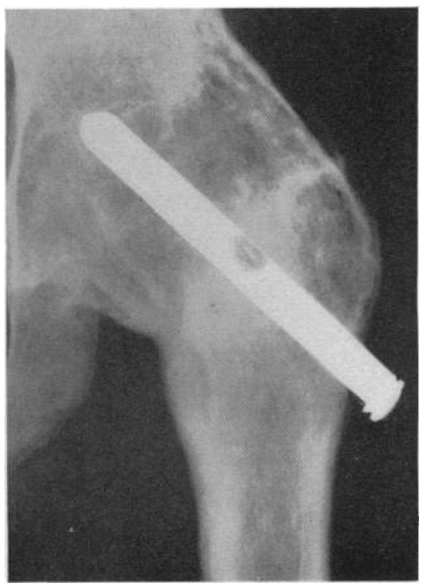

FIG. 4.—Nail A.606 nine years after insertion.

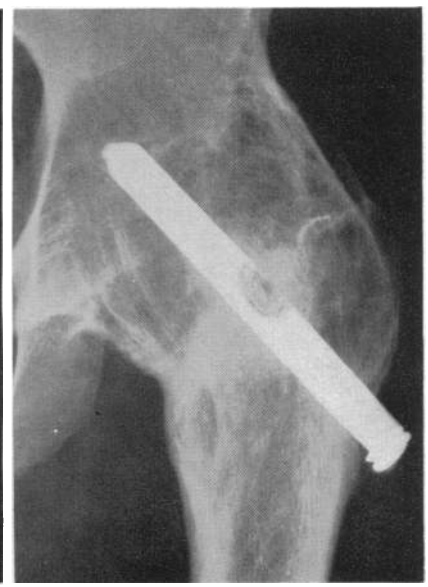

FIG. 5.—Nail A.606 17 years after insertion.

FIG. 6.—Nail A.460. Antero-posterior radiograph of left hip showing zone of reaction around corroded nail. Note that deep corrosion pits are scarcely visible in this view.

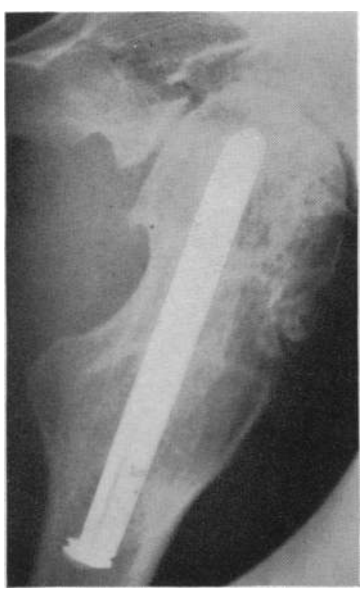

FIG. 7.—Nail A.460. Lateral radiograph of left hip. Note corrosion pits in distal third of nail and zone of reaction in bone.

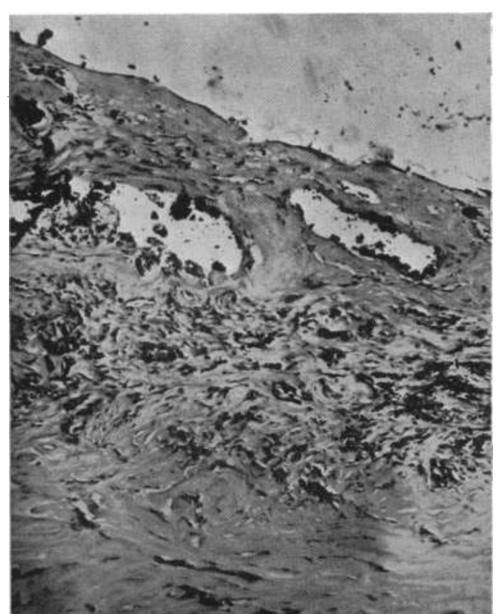

FIG. 8.—Nail A.46. Tissue from around 13% Cr nail after eight years.

made of two pieces, the head having been screwed on to the nail. When the heads were unscrewed a small quantity of grey-green powder and some metal particles were found to be trapped in the threads. To reduce the risk of corrosion, all implants should be cleaned by one of the established methods ; this is particularly important in the case of composite hollow implants. All the nails were inserted between 1954 and 1959 and remained in the body for periods between 18 days and five years. The patients varied in age between 15 and 82 years, the average age being 64 years. The nails were used for fractures of the femoral neck (23), slipped femoral epiphysis (2), arthrodesis of the hip (1), osteotomy (1), and arthrodesis of the shoulder (1). The reasons for removal of the nails are given in Table V. More details concerning the corroded nails and the reasons for their removal appear in Table VI.

A typical example of corrosion of a two-piece nail was shown by A.7, the head of which is illustrated in Fig. C. Corrosion had taken place at the junction between the head and stem, as reproduced at higher magnification in Fig. D. A section through the junction is shown in Fig. E. Though in this particular example corrosion had occurred only at the outer surface. a gap, such as can be seen in Fig. F, between the threaded portion of the stem and head favours corrosion of the "shielded type." Nineteen of the nails were extruded, and it was usually found at operation that the implant was quite loose in the femoral neck. This extrusion was associated with infection in three cases and with avascular necrosis of the femoral head in five cases. By virtue of its weight, shape, and the position in which it is inserted, a hip nail is liable to extrude, and this tendency is accentuated by the inevitable vibration present in a living organism. As with the 18/8 implants, there was no correlation between visible corrosion and the radiographic appearances and clinical histories of the patients.

TABLE V.—*Reasons for Removal of 18/8/Mo Nails*

Principal Reason for Removal	No. of Nails	No. of Nails Corroded
Simple extrusion	11*	3
Extrusion and infection	3	—
Extrusion with avascular necrosis	5	1†
Non-union	2	1
Non-union with penetration into acetabulum	2	1
Avascular necrosis	1	1
Routine	2	1†
Refracture of femoral neck due to fall	1	—
Pain	1	1
Total	28	9

* Including nail used for arthrodesis of shoulder. † Pidcock pin only.

18/8/Mo Alloy and 18/8 Alloy Mixed

There was one nail manufactured of two pieces in which the head had been made from 18/8/Mo alloy and the stem from 18/8 alloy. The head of the nail was marked with the code letter for 18/8 alloy. There was slight pitting corrosion on the threads within the head. The nail had been used in a male aged 41 years for arthrodesis of the hip, and was removed after 34 months because of gradual extrusion of the nail and the presence of a discharging sinus leading down to the implant. The organism isolated was a coagulase-negative staphylococcus. There was a small area of rarefaction in the

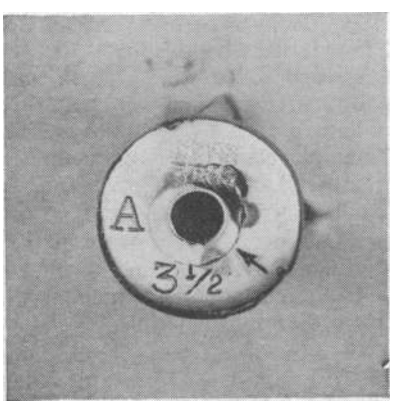

FIG. C.

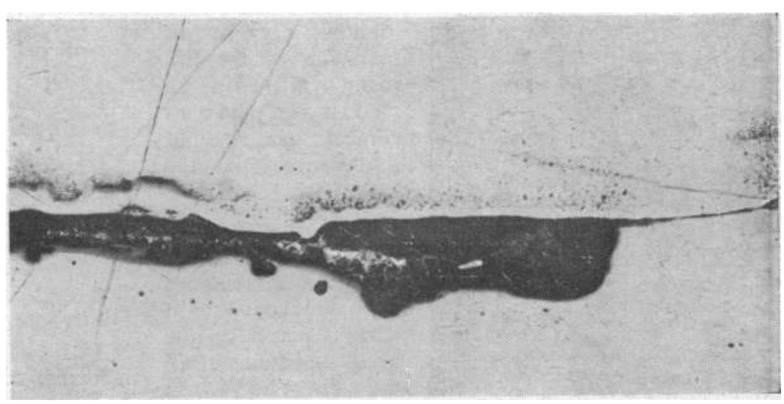

FIG. D.

FIG. C.—Nail A.7. (Maker's name removed.) Corrosion at junction between head and stem of 18/8/Mo nail (arrowed). Marks at 3 and 5 o'clock are initial spark spectroscopy burn marks. After sectioning composition of head and stem was confirmed. (×2.) FIG. D.—Nail A.7. Showing corrosion (×100) at junction of head with stem at site indicated by arrow in Fig. C.

TABLE VI.—*Situation of Corrosion and Reason for Removal of 18/8/Mo Nails*

Nail No.	Date Inserted	Time in Body (Months)	Construction of Nail	Situation of Corrosion	Condition Treated	Reason for Removal
A.7	1954	10	Two-piece: head 18/8/Mo; stem 18/8/Mo	Junction of stem with head	Slipped femoral epiphysis (R)	Avascular necrosis of femoral head
A.327	1957	6	One-piece	Carburization of cannula wall and pits on head surface	Fractured neck of femur (R)	Non-union with penetration into acetabulum
A.392	1956	17	Two-piece: head 18/8/Mo; stem 18/8/Mo	Corrosion of threads of stem and head	,, ,, ,, (L)	Simple extrusion
A.432	1958	¾	One-piece	Pits in cannula	,, ,, ,, (R)	,, ,,
A.462	1956	24	One-piece + 18/8/Mo Pidcock pin	Pitting on Pidcock pin	,, ,, ,, (L)	Routine
A.594	1958	15	,, ,, ,,	Pitting with fracture of Pidcock pin	,, ,, ,, (L)	Extrusion with avascular necrosis
A.691	1959	10	One-piece	Shallow pitting on one flange near head	Perthes's disease (osteotomy) (L)	Pain
A.695	1958	20	,,	Carburization of cannula	Fractured neck of femur (R)	Non-union
A.704	1957	1	,,	Carburization of cannula and corrosion in areas showing impactor marks	,, ,, ,, (R)	Simple extrusion

bone over the superior border of the nail in the lateral cortex seen in a radiograph taken 31 months after operation.

Group 3: Cobalt–Chromium–Molybdenum Alloy

Two nails made from Co–Cr–Mo alloy were examined. There was no sign of corrosion on either of these nails. Both had been used for fixation of fractures of the femoral neck in patients aged 53 and 56 years

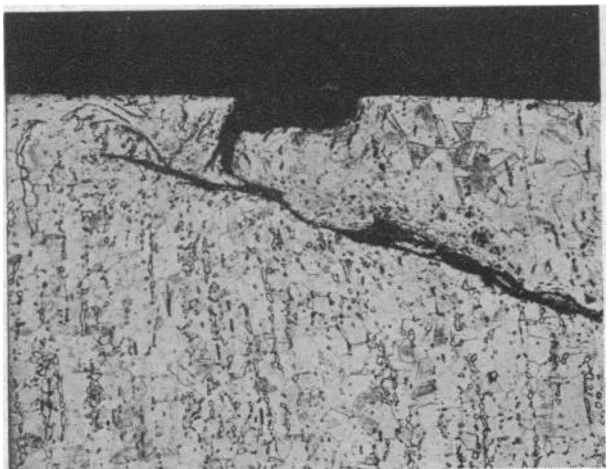

FIG. E.—Nail A.7. Section through junction of head with stem. (×150.)

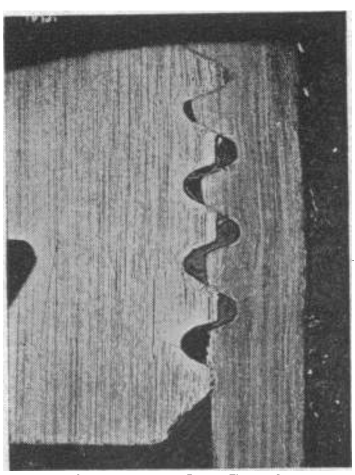

FIG. F.—Nail A.7. Gap between threads of head and nail. Contained blackish powder with metal particles.

respectively, and were removed after five months and 28 months because of extrusion of the implant. There was no radiographic or clinical evidence of intolerance to the nails.

Hardness

Hardness readings were taken from various places on the heads and stems of all the nails. The Vickers "diamond pyramid" hardness number on the stem of the majority of austenitic nails lay between 150 and 270. This approximately corresponds to a tensile-strength range between 33 and 59 tons per square inch (52 and 93 kg. per sq. mm.). It was found, however, that there was considerable variation in hardness on different areas of an implant. For example, in one 18/8 nail the head gave readings of 316–317 and the stem 168–175. The steel as supplied will usually be in the softened condition, but any of the manufacturing processes—for example, grinding, milling, and polishing—will cause local increase in hardness. The hardness of the head will be increased when the nail is hammered into the femur. This was confirmed on a new 18/8/Mo nail, the hardness of the head being raised from 190–205 to 262–306 by a single blow of the hammer.

The effect of work hardening may be illustrated by a series of readings from a piece of En.58J (18/8/Mo) steel sheet. As supplied this had a polished surface (hardness 160–178; 48 readings) and an unpolished surface (hardness 155–169; 48 readings). After lightly filing the polished surface (30 strokes with moderate pressure with a No. 1 cross-cut file) the hardness increased to 164–197 (40 readings). Local differences in the physico-chemical properties of the surface of the implant can thus be caused by work hardening produced during manufacture, by hammering at insertion of the implant, and by stresses in the body which may cause the nail to bend. There was no evidence that local differences in hardness led to visible corrosion on the implants we have examined.

Mismarking

Spark spectroscopy established that a number of the implants had been mismarked by the manufacturer: eight one-piece 18/8/Mo nails marked for 18/8; one one-piece 18/8 nail marked for 18/8/Mo; two one-piece 18/8/Ti nails marked for 18/8; one 18/8/Mo head on 18/8 stem—head marked for 18/8.

Summary

Sixty-five Smith-Petersen type hip nails and four Pidcock pins removed from patients have been examined. Corrosion was detected on 26 nails and three Pidcock pins. Most of the implants were removed for reasons other than corrosion, but in at least three cases corrosion was the reason for removal.

13% Cr implants which should have been discarded before 1940 had been used in nine patients, the most recent case having been treated in 1959; all the nails were found to be corroded. Two nails of 17% Cr, 2% Ni, one inserted in 1947, the other in 1959, were corroded. This is another unsuitable alloy. 30% of 18/8/Mo implants showed corrosion. There was carburization of the wall of the cannula of one 18/8 and three 18/8/Mo implants. This condition results from certain methods employed in the manufacture of thick-walled tubing from which some Smith-Petersen nails have been made in the past.

The steel implants were made from five types of ferrous alloy, all of which can corrode in the human body. It is preferable to machine the whole of the Smith-Petersen nail from the solid material.

The code letter denoting the type of steel was incorrect on 11 nails. The marking of implants either by punching or by electrolytic methods has not predisposed to corrosion.

The corrosion resistance of the high-alloy steels examined does not appear to be related to hardness or to local variations of hardness.

We would like to thank the following for the supply of implants, case histories, and radiographs which formed the material for this investigation: D. M. Brooks, H. Jackson Burrows, J. W. Dickson, A. T. Fripp, J. I. P. James, A. P. Kitchin, C. W. S. F. Manning, P. H. Newman, K. I. Nissen, R. Y. Paton, J. H. Penrose, H. J. Seddon, D. Trevor, and J. N. Wilson. The help we have received from many registrars and the staff of medical records departments of a number of hospitals is gratefully acknowledged. We are indebted to the General Electric Company, Applied Electronics Laboratory, Stanmore, for their co-operation in certain aspects of this work. We would like to thank Miss R. Chomed, Department of Biomechanics and Surgical Materials, for her secretarial efforts in the whole investigation.

REFERENCE

Scales, J. T., Winter, G. D., and Shirley, H. T. (1959). *J. Bone Jt Surg.*, **41B**, 810.