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CRUSH INJURIES WITH IMPAIRMENT OF RENAL FUNCTION

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[WITH SPECIAL PLATE]

Amongst air-raid casualties seen at this hospital have been four cases of crush injury of the limbs which, because of the general similarity of their clinical course, were thought to represent a specific and hitherto unreported syndrome, and one which has been and will be seen elsewhere during the war. Such a condition may have been observed in civil practice, but we have been unable to find any account of it in the literature. The cases are of interest on account of the problem propounded by both pathogenesis and treatment. The picture presented by these four cases, and substantiated by others, is briefly as follows:

The patient has been buried for several hours with pressure on a limb. On admission he looks in good condition except for swelling of the limb, some local anaesthesia, and whealing. The haemoglobin, however, is raised, and a few hours later, despite vasoconstriction, made manifest by pallor, coldness, and sweating, the blood pressure falls. This is restored to pre-shock level by (often multiple) transfusions of serum, plasma, or occasionally, blood. Anxiety may now arise concerning the circulation in the injured limb, which may show diminution of arterial pulsation distally, accompanied by all the changes of incipient gangrene. Signs of renal damage soon appear,

and progress even though the crushed limb be amputated. The urinary output, initially small, owing perhaps to the severity of the shock, diminishes further. The urine contains albumin and many dark brown or black granular casts. These later decrease in number. The patient is

alternately drowsy and anxiously aware of the severity of his illness. Slight generalized oedema, thirst, and incessant vomiting develop, and the blood pressure often remains slightly raised. The blood urea and potassium, raised at an early stage, become progressively higher, and death occurs comparatively suddenly, frequently within a week. Necropsy reveals necrosis of muscle and, in the renal tubules, degenerative changes and casts containing brown pigment.

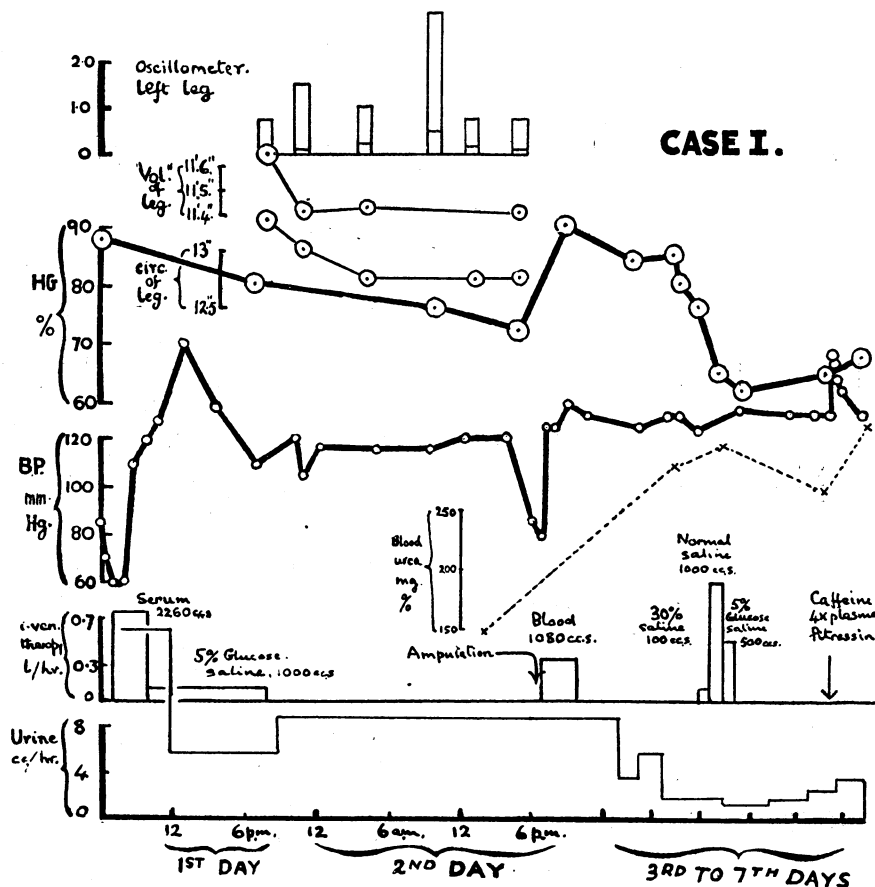


CHART I.—Case I.

Case I

A female aged 17 had been buried for nine hours with heavy masonry lying across the left leg. On admission she showed slight bruises generally, and multiple superficial abrasions below the left knee. The leg was swollen and sensation was impaired at the ankle, where all power and movement were lost. Other limbs appeared undamaged. The skin was pallid and clammy; the blood pressure was 85/70 mm. Hg. The clinical course is shown on Chart I. Recalcified plasma-saline (Clegg and Dible, 1940) (subsequently referred to as "serum"), followed by 5% glucose-saline,

brought the blood pressure from 60 mm. Hg. where it had remained for one and a half hours, to 160 mm. Hg. Urine was passed containing neither albumin nor blood.

By 7 p.m. the haemoglobin concentration had fallen. Blisters were forming on the left knee, where there was a joint effusion. Less oedema of the leg was now present than on admission; measurements were made of leg circumference, of leg volume (by a tape method),* and of pulsation by means of an oscillometer. During the next twenty-four hours the volume and circumference of the leg decreased. However, the oscillometer readings, after a deceptive rise towards normal, fell to the low initial level, even though during this

TABLE I.—Biochemical Findings in Case 1: Blood

| Date | Time | Urea mg. per 100 c.c.m. | Plasma Inorg. P mg. per 100 c.c.m. | Plasma Chlorides (as NaCl) mg. per 100 c.c.m. | Plasma Proteins | | | | Alkali Reserve c.c.m. | Serum Potassium mg. per 100 c.c.m. |
|--------|-------------------------|----------------------------|---------------------------------------|---|-----------------------------|-------------------------------|--------------------------------|----------------------------------|--------------------------|---------------------------------------|
| | | | | | Total gm. per 100 c.c.m. | Albumin gm. per 100 c.c.m. | Globulin gm. per 100 c.c.m. | Fibrinogen gm. per 100 c.c.m. | | |
| Dec. 5 | 2 p.m. | 148 | — | 584 | 6.9 | 4.0 | 2.8 | 0.1 | 50 | 30 |
| " 7 | 10.40 a.m. | 286 | — | 498 | — | — | — | — | 42 | — |
| " 8 | 11 a.m. | 305 | 7.3 | 615 ² | 6.2 | — | — | — | 40 | 31 ³ |
| " 10 | 2.30 p.m. | 268 | — | 575 | — | — | — | — | — | 33 |
| " 11 | 12.20 p.m. ¹ | 320 | 7.7 | 496 | 6.6 | 3.7 | 2.7 | 0.2 | — | 34 ⁴ |

¹ At death.

² Received 1,000 c.c.m. of saline.

³ Uric acid 10.8 mg., creatinine 2 mg., plasma sodium 307 mg.

⁴ Serum calcium 9.1 mg.

TABLE II.—Biochemical Findings in Case 1: Urine

| Date | Time | Volume c.c.m. | Protein mg. per 100 c.c.m. | Urea mg. per 100 c.c.m. | Chlorides (as NaCl) mg. per 100 c.c.m. | Benzidine Reaction | Deposit |
|------|------------------------|------------------|-------------------------------|----------------------------|--|-----------------------|--|
| | | | | | | | |
| " 6 | { 10.30 a.m. 5 p.m. | { 332 22 | { 60 350 | { — — | { 270 360 | { Positive " | Hyaline, red cell, and granular casts Pus cells bacteria |
| " 7 | 7.30 a.m. | 80 | 800 | — | 560 | " | |
| " 8 | 11 a.m. | 50 | 1,000 | 514 | 520 | " | |
| " 9 | 10 a.m. | 30 | 900 | — | 480 | " | |
| " 9 | 9 a.m. | 38 | 900 | 570 | 520 | " | |
| " 10 | 5.55 p.m. | 4.5 | — | 720 | 440 | " | |
| | 6.45 p.m. | 14.2 | — | 680 | 440 | | |
| | 8 p.m. | 4.8 | — | 770 | 440 | | |
| " 11 | 9 p.m. | 3.4 | — | 750 | 410 | " | |
| | 10 p.m. | 2.2 | — | 740 | 420 | | |
| " 11 | 9.15 a.m. | 38 | — | 770 | 420 | " | |

period the left leg had been bandaged and elevated to 50 degrees on a Thomas splint for two hours. The second specimen of urine still showed neither albumin nor blood.

By 6 p.m. the next day the left leg was cold below the knee and blue, and amputation was proposed. This was done under vinesthene and gas-and-oxygen. Citrated stored blood (Group O) was given during and after operation, restoring the blood pressure, which had temporarily fallen, to the pre-operative level. Urines collected after this showed albumin and gave a positive benzidine reaction; hyaline, granular, and what appeared to be red cell casts were noticed, besides free red corpuscles.

During the next five days the patient continued drowsy

* Worked out in conjunction with D. K. Hill. An inextensible tape of width (w) is wound round the limb without overlapping. The length of tape (L), thus enclosing a certain volume (V) by a number of turns (n), is given by the formula:

$$L = \sqrt{\frac{411nV}{kw}}$$

where k is a constant dependent on the shape of the leg. In Case I direct measurement of volume by water displacement gave k a value of 0.90.

and apathetic, from which state she was easily roused by the slightest stimulus to become anxious and apprehensive, without, however, any loss of mental clarity. The output of urine became very small, despite a fluid intake by mouth of between 1.5 and 2.5 litres daily; vomiting continued (between 50 and 250 c.c.m. daily). Normal saline (1 litre), 30% saline (100 c.c.m.), and 5% glucose-saline, followed later by caffeine benzoate (140 mg.), 85 c.c.m. of four-times-normal reconstituted dried serum (obtained from the Medical Research Council serum-drying unit), with, in addition, pitressin 1/100,000, were given intravenously, and hot bottles were applied to the loins. Despite these measures, directed towards restarting urine flow, the patient, whose blood pressure was maintained at 130/70, suddenly collapsed at 12.13 p.m. on the eighth day and died in three minutes. A systolic murmur at the apex and dropped beats had been noticed for forty-eight hours before death, and an electrocardiogram taken forty-one hours before death showed merely low voltage. A second, sixteen hours later, showed widening of QRS, higher voltage, increase in Q_s, and inversion of T_s. Biochemical findings are listed in Tables I and II. Necropsy was performed two and a half hours after death.

SUMMARY OF POST-MORTEM RECORD BY DR. THOMAS BELT

The point of major interest was the condition of the kidneys. They were large, weighing 210 and 230 grammes respectively, rather dark red and firm, quite smooth of surface, having tense capsules due to swelling of the cortices. The cut edges everted; the cut surfaces were wet and glassy owing to oozing of serous fluid. Parts of cortex midway between renal pyramids were blanched by a zonal ischaemia. There was no evidence of ascending infection. The bladder was slightly reddened, and contained a few drops of very thick cloudy urine. Subcutaneous and retroperitoneal tissues oozed serous fluid when cut, indicating a slight generalized oedema. Marked cyanosis was evident in the internal parts, but the skin was pale. Other organs and tissues presented no striking change.

Microscopical Examination.—Kidney: The main change was to be found in the tubules. The convoluted tubules and the loops of Henle were severely damaged. The cytoplasm of the lining epithelium was swollen, frayed, granular, and vacuolated. Individual cells here and there were devitalized and desquamated, while those that remained attached showed fairly frequent mitotic figures. The cast-off cells in various stages of disintegration merged in the lumina with loose collections of eosinophilic debris. In the loops of Henle and the collecting tubules there were numerous casts of dense eosinophilic material, most of which had a brownish colour, as though lightly stained with bile or blood pigment. These casts seemed to be all of the same substance, though their morphological appearance varied a good deal, depending upon the degree of condensation they had undergone. Some looked not unlike collections of disintegrating erythrocytes; others simulated shreds of fibrin or beaded ribbon, while still others were condensed into solid hyaline cylinders. They seemed to be compounded of dead epithelial cells, inspissated albumin, and perhaps hyaline material exuding from the lining of the tubules. One could identify an occasional erythrocyte within the tubules, but, so far as could be determined by histological means, the majority of the casts were not red cell casts, though some of their colour might have been due to haemoglobin. They were probably not of a specific type, as similar casts are to be seen in acute nephritis and other conditions where there seems to have been great reabsorption in the tubules, resulting in a scanty concentrated urine. Some of them were surrounded and invaded by leucocytes, and, in the lower reaches of the straight tubules, leucocytes were sometimes the predominant constituent. Here and there a cast-filled tubule was undergoing disintegration and was surrounded by inflammatory cells. Stains for iron were negative. Fatty changes were absent. The glomeruli showed no obvious structural change, though the frequent presence of albuminous material in Bowman's capsule suggests that they had not escaped injury. The glomerular tufts contained relatively little blood, but the vessels of the medullary parts were greatly engorged.

Other Tissues.—Thyroid: Signs of commencing activity with increased height of cells and many mitoses. Liver: cloudy

swelling but no necrosis. Adrenal: patchy loss of cortical lipid. Heart: vacuolation of neuromuscular fibres (bundle of His). Muscles of right leg: not abnormal.

The amputated leg showed haemorrhage in the popliteal fossa around the artery, extending along the intermuscular fascial planes. There was no oedema beneath the deep fascia, but slight superficial oedema with punctate haemorrhage was present over the pressure areas in the skin. There was a haemarthrosis of the knee-joint, with cracks in the patella and tibial cartilages, extending down across the bone of the tibial condyle. Sections of artery showed no lesion; sections of muscle (which macroscopically looked normal) revealed a few fibres (1%) undergoing necrosis, with loss of striation and staining power.

Case II

A female aged 45 had been crushed under a collapsed building for six hours. On admission there was a large scalp wound and lacerations and bruises of both legs, on which

raised urea (115 mg.), plasma chloride (801 mg. as NaCl), and serum potassium (28 mg.), and a lowered CO₂-combining power (41 c.c.m. per 100 c.c.m.). Pulsation had returned in the right leg but not yet in the left. The chloride content of the body was therefore reduced (by sweating, purgation, and replacement of gastric juice by sodium bicarbonate) and the oedema disappeared, except from the legs. During the next three days her condition remained the same: the blood pressure reached as high as 168/104, and, while the plasma chloride and alkali reserve fell, urea, phosphates, and potassium steadily rose. Urinary output was very low (50 c.c.m. daily) in spite of a daily intake of between 1½ and 2 litres. The urine became blood-free but infected (catheterization), and showed a low chloride concentration.

On the sixth day at 11.15 p.m. the patient became distressed, cold, and wet with sweat: a systolic murmur was heard at the apex and the blood pressure fell to 106/85. An electrocardiogram taken before this (at 7 p.m.) showed bundle-branch block. The pulse suddenly fell to 70 (previously

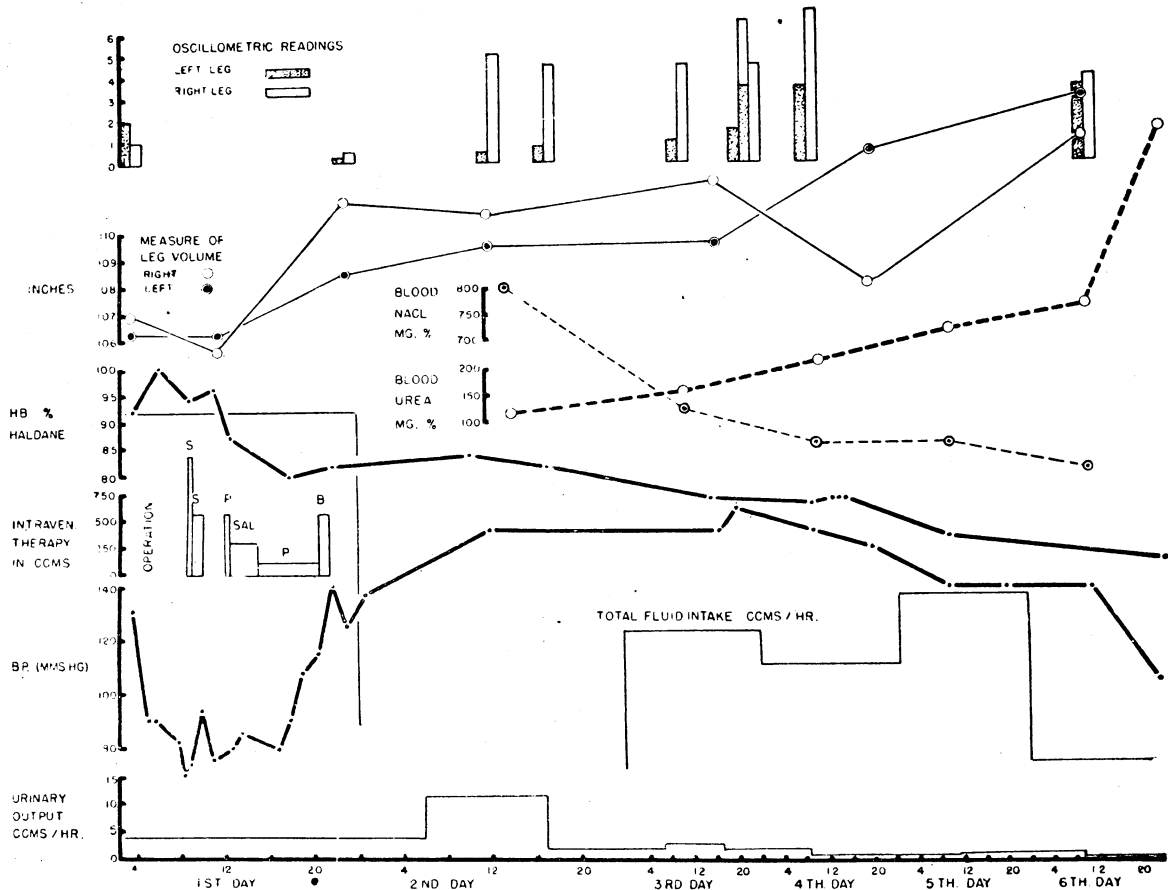


CHART II.—Case II.

debris had been pressing. Both calves were extremely hard, swollen, and tense. The blood pressure was 130/98, and, despite considerable bleeding from the scalp, the haemoglobin amounted to 92%; the pulse was 130. (See Chart II.) Measurements were taken of leg volume. Pulsation (oscillometer) was decreased in both legs. The scalp wound was sutured under gas-and-oxygen and ether.

Two hours later haemoconcentration developed and the blood pressure fell. Repeated infusions of "serum," plasma, and saline restored the blood pressure to 115 mm. Hg; then, following a transfusion of citrated stored blood, to the abnormally high level of 160 mm. Hg. With the rise in blood pressure the volumes of both legs increased, and the oscillometric readings fell. Dark smoky urine was obtained by catheter next day, showing albumin and red cell and hyaline casts.

At 2 p.m. she was vomiting and had oedema of the face, eyelids, and arms as well as the legs. Venous blood showed

steady at 100) and showed dropped beats. She died at 12.10 a.m. on the seventh day. Biochemical findings are shown in Tables III and IV.

TABLE III.—Biochemical Findings in Case II: Blood

| Date | Time | Urea | Plasma norg. P | Plasma Chlorides (as NaCl) | Plasma Protein | Serum Potassium | Alkali Reserve |
|--------|------------|--------------------|--------------------|----------------------------|--------------------|--------------------|----------------|
| | | mg. per 100 c.c.m. | mg. per 100 c.c.m. | gm. per 100 c.c.m. | gm. per 100 c.c.m. | mg. per 100 c.c.m. | c.c.m. |
| Dec. 5 | 2 p.m. | 115 | — | 801 | 7.1 | 28 | 41 |
| " 6 | 11 a.m. | 156 | — | 572 | — | — | 40 |
| " 7 | 11 a.m. | 214 | 11.1 | 513 | — | — | 40 |
| " 8* | 10.30 a.m. | 270 | 9.2 | 513 | 6.9 | — | 34 |
| " 9 | 11 a.m. | 314 | 12.9 | 464 | — | 32 | 30 |
| | at death | 640 | — | — | — | 34 | 30 |

* Uric acid 10 mg., creatinine 2 mg., and serum sodium 290 mg.

TABLE IV.—Biochemical Findings in Case II: Urine

| Date | Time | Volume | Protein | Urea | Chlorides (as NaCl) | Benzidine Reaction | Deposit |
|--------|------------|--------|-------------------|-------------------|---------------------|--------------------|--|
| | | c.cm. | mg. per 100 c.cm. | mg. per 100 c.cm. | mg. per 100 c.cm. | | |
| Dec. 5 | 6 a.m. | 92 | 400 | — | 160 | Positive | Dark and smoky casts. Many red cells, few granular casts |
| | 5.15 p.m. | 134 | — | — | 180 | | |
| " 6 | 7.30 a.m. | 25 | 400 | — | 240 | " | Red cells. Red cell casts. Pus cells |
| | 5 p.m. | 20 | 300 | — | 180 | | |
| " 7 | 8.30 a.m. | 21 | 160 | — | 180 | " | Pus. Microorganisms. Few red cells |
| " 8 | 11.30 a.m. | 15 | 400 | 520 | 240 | " | |
| " 9 | 10 a.m. | 16 | 900 | — | 320 | " | |
| | at death | 16 | 800 | 670 | 240 | " | |

SUMMARY OF POST-MORTEM RECORD BY DR. THOMAS BELT

Necropsy twelve hours after death: Calf muscles on both sides showed widespread necrosis. They were blanched and swollen as if parboiled, and mottled with haemorrhagic areas. The vessels of the legs were apparently undamaged. The kidneys were relatively large (weighing 190 and 170 grammes), smooth, tense, and dark red. There was no pyelitis. The bladder mucosa was slightly reddened; the liver was swollen (1,830 grammes); and the lungs were slightly oedematous (500 grammes each).

Microscopical Examination.—Kidney changes were very much like those in Case I. There were perhaps more leucocytes in the tubules, and these occasionally extended right up into the cortex. The liver showed cloudy swelling but no necrosis. Muscle displayed widespread necrosis, chiefly coagulative but becoming liquefactive in small foci. There was much patchy haemorrhage and polymorph reaction in disintegrating areas, but no bacteria. Some small vessels in the section showed necrosis of the wall. The pancreas had a few patches of fat necrosis, and the adrenal gland showed patchy loss of cortical lipid. Other tissues appeared normal.

Case III

A male aged 34 was pinned down by beams across shoulders, arms, and thighs for twelve hours. On admission he was pale and shocked, with great swelling of both arms and thighs, and skin-whealing at pressure sites. There was occasional vomiting (about 120 c.cm. daily). The blood pressure could not be taken on account of the swelling. 1,900 c.cm. of "serum" was given intravenously over ninety minutes, reducing the haemoglobin from 160 to 112%. (See Chart III.) Next day the left arm appeared greatly swollen, and the hand blue, cold, and pulseless. An incision was therefore

made from mid-arm to below the elbow, relieving the tension beneath the deep fascia so that the brachial artery again began to pulsate. This was followed by a transfusion of 460 c.cm. of blood (Group O). Urine was passed—specific gravity 1015—containing albumin and blood but no casts. On the third day the left hand was warm but still devoid of sensation and power: there was oedema of both thighs, but a radiograph showed that there was no bony lesion. The patient continued to vomit about 100 c.cm. daily; 6 litres of 5% glucose-saline had been given intravenously over this and the previous day. There was some incontinence of urine, of which, however, 655 c.cm. was collected. On the fourth day, despite a fluid intake of 1,340 c.cm., 590 c.cm. of urine was passed, still containing albumin. At 5 p.m. the temperature rose suddenly to 103.4°, and there was some redness around the site of the intravenous puncture. Sulphapyridine by mouth was started. On the fifth day vomiting, dyspnoea, and slight generalized oedema occurred, with crepitations at both bases and a pleuro-pericardial friction rub. A radiograph revealed slight basal congestion only; an electrocardiogram showed right axis deviation; the blood pressure was abnormally high (170–180 mm. Hg), and, despite a urinary output of 990 c.cm. in the day (on an intake of 1,230 c.cm.); the blood urea was 260 mg., the total plasma protein 8.0 grammes, and the plasma chlorides (as NaCl) 500 mg. per 100 c.cm.

During the sixth day the blood pressure fell progressively without further concentration. At 8 p.m. the patient had become delirious and disorientated, and the pulse rapid. The skin became cold, wet, and cyanosed. Coarse crepitations were heard at both bases: there was incontinence of urine, of which 530 c.cm. was collected, showing albumin and numerous red cells but no casts in the deposit. Oxygen was given. The fluid intake was 1,860 c.cm. The blood urea was 326 mg., the total plasma proteins 4.8 grammes, and the plasma chlorides (as NaCl) 500 mg. per 100 c.cm.

Death occurred on the seventh day. 160 minutes before death the blood urea was 345 mg., the total plasma proteins 6.1 grammes, the plasma chlorides (as NaCl) 461 mg., and the serum potassium 33 mg. per 100 c.cm.

SUMMARY OF POST-MORTEM RECORD BY DR. THOMAS BELT

Necropsy showed staphylococcal pyaemia due to thrombophlebitis of saphenous veins. There was extensive crushing of leg muscles. Micro-

scopically, tubular changes in the kidneys resembled those of Cases I and II. There were numerous casts of similar character, but the picture was somewhat complicated by the presence of a few small pyaemic abscesses.

Case IV

A male aged 16 was buried under a collapsed house for eight hours, the left thigh being pinned down by a heavy load of masonry. On admission the systolic blood pressure was 140 mm. Hg, and superficial abrasions were present on the left thigh, later becoming whealed. On getting out of bed that afternoon he fainted. At 8 p.m. he suddenly collapsed; the haemoglobin had risen to 140% and the blood

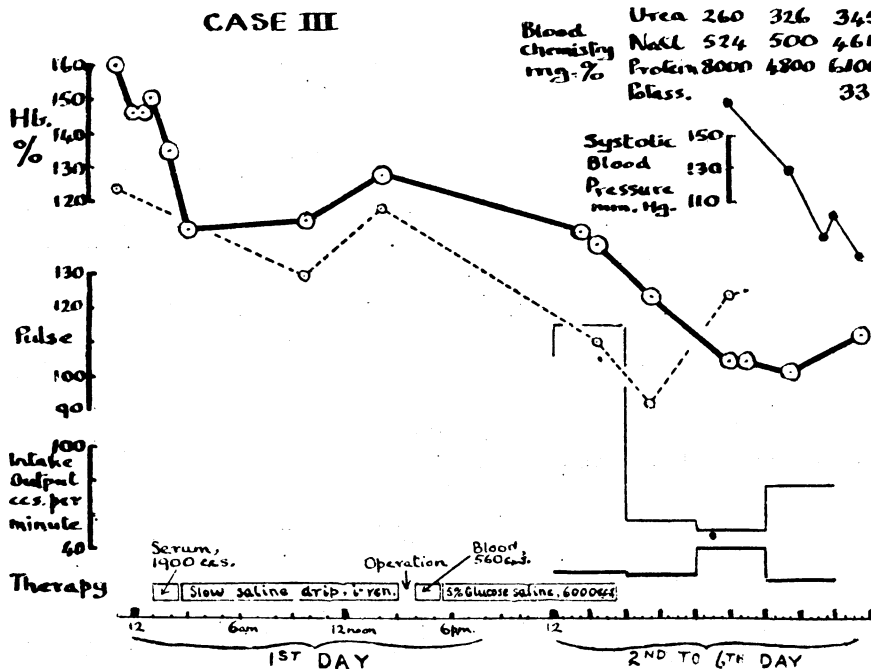


CHART III.—Case III, including biochemical data.

E. G. L. BYWATERS AND D. BEALL: CRUSH INJURIES WITH RENAL CHANGES

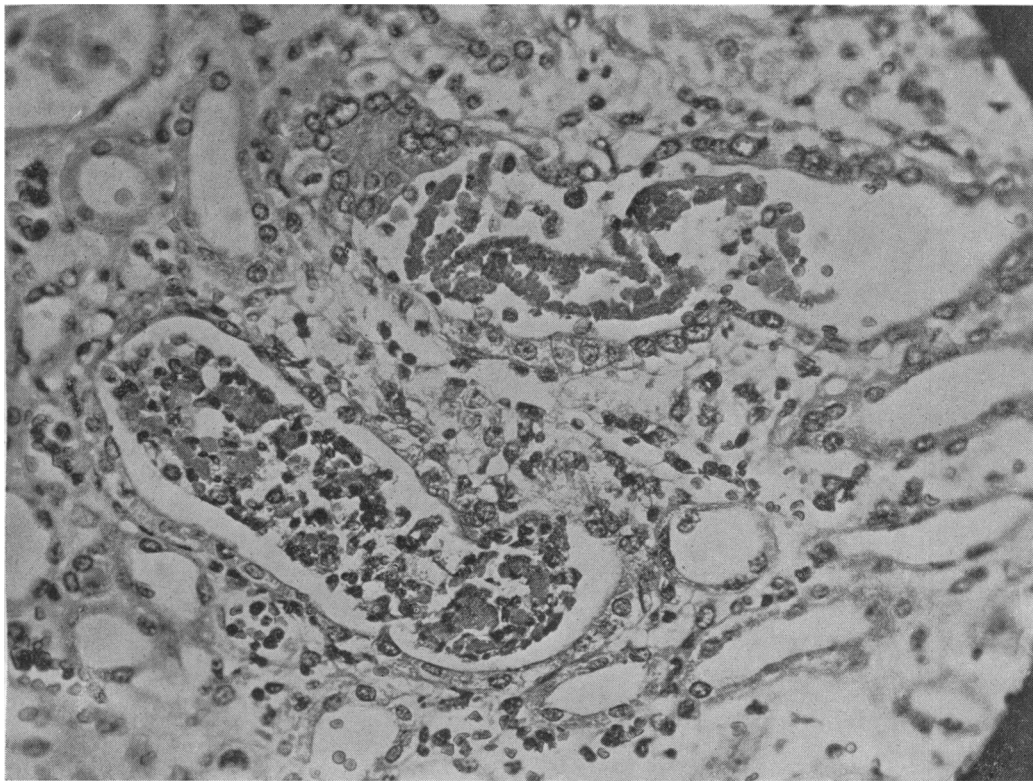


FIG. 1.—Photomicrograph of renal collecting tubules from medulla, stained haematoxylin and eosin, showing, above, ribbon-like pigmented cast, and, below, similar cast invaded by polymorphs and surrounded by desquamated epithelial cells. $\times 300$.

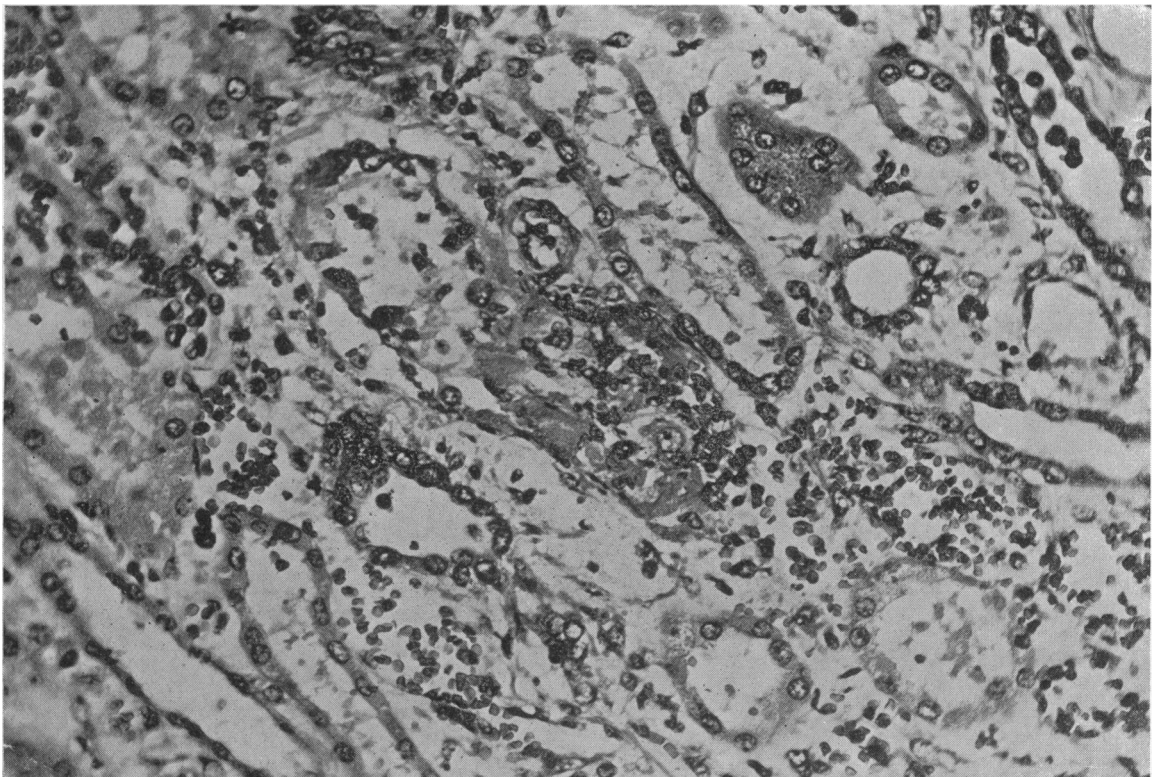


FIG. 2.—Photomicrograph of renal tubule from boundary zone, stained haematoxylin and eosin, showing necrosis of wall and commencing reactive changes. $\times 280$.

pressure had fallen to 40 mm. Hg; the pulse rate was 108 per minute. Venous blood showed plasma protein to be 9.1 grammes and chlorides (as NaCl) 545 mg. per 100 c.cm. He was given normal saline, and then "serum" intravenously, which, as may be seen from Chart IV, brought the blood pressure to 96 mm. Hg, and the haemoglobin down to 85%; plasma protein was 7.9 grammes and chlorides (as NaCl) 705 mg. per 100 c.cm. This was immediately followed by serum, which effectively lowered the haemoglobin and

be accounted for either by excretion into the lumen from the blood stream of haemoglobin, myohaemoglobin, or bile pigment, or possibly by the extrusion into the lumen of cells already pigmented.

Changes very similar to these are described following mismatched transfusion (Witts, 1929; Goldring and Graef, 1936; Baker, 1937). There is the same absence of changes in glomeruli, and similar changes in the convoluted tubules, in the interstitial tissue, and in the straight tubules. The casts are not composed of red cells, but sometimes there are spherical bodies resembling them. Baird and Dunn (1933) and others have noted similar casts containing "haemoglobin" in eclampsia.

The effect on function of blockage by casts is obscure: if this were the only lesion, what urine was secreted (through unobstructed tubules) should be of normal composition. The urine resembled, however, more a glomerular filtrate; there was no significant concentration of urea (hence no selective absorption of water), and in Case I there was failure to reabsorb chloride when the blood level was below 500 mg. per 100 c.cm. Case II showed some degree of chloride reabsorption. There thus appears to be dysfunction of the convoluted tubules. Whether partial blockage or blockage of a few tubules—cf. the kidney after mismatched transfusion, in multiple myeloma (Forbus *et al.*, 1935; Holman, 1939), and in calcification affecting the pyramids (Albright *et al.*, 1940)—can so raise the intrarenal pressure as to interfere with tubular function as well as with glomerular filtration is not known. It has recently been suggested (Navasquez, 1940) that the degree of tubular blockage is not sufficient to account for the symptoms associated with "transfusion kidney." The hypertension in Cases II and III, and also noted in the case reported elsewhere in this issue (Mayon-White and Solandt, p. 433), may be allied to other types of primary "renal hypertension."

It is possible that minor degrees of this renal damage may occur, since at least one patient with crushed limbs has been observed to recover completely (R. V. Christie, personal communication) with a raised blood urea and low urea clearance. In a similar case of muscle crush seen elsewhere (Beall, Belsey, Bywaters, and Miles, unpublished data) there was a definite tendency towards recovery of renal function, shown by the increasing resorption of both water and chloride. Certain cases of post-operative anuria may prove to fall into this category, but the majority of them appear to be associated mainly with decreased blood volume and blood pressure, since restoration of blood volume to normal improves the renal output.

In Case I fibroblast increase and tubular dilatation were much more prominent than in the other cases. The latter may in part be related to the strong therapeutic stimulation, as caffeine raises the glomerular capillary pressure, with a resultant increase in filtrate (Verney and Winton, 1930).

Aetiology of the Syndrome

Muscle necrosis is the one aetiological factor common to these cases and to those observed elsewhere. It was of limited extent in Case I, although comparison with the degree of necrosis in the other cases is difficult, since the leg was removed thirty-six hours after admission. It would seem of some significance that, in spite of amputation in this case, the time interval between injury and death was of the same order as in the others.

It is known that when muscle is injured its permeability increases and intracellular ions such as potassium leave it rapidly (Horton, 1930). This may be related to the early

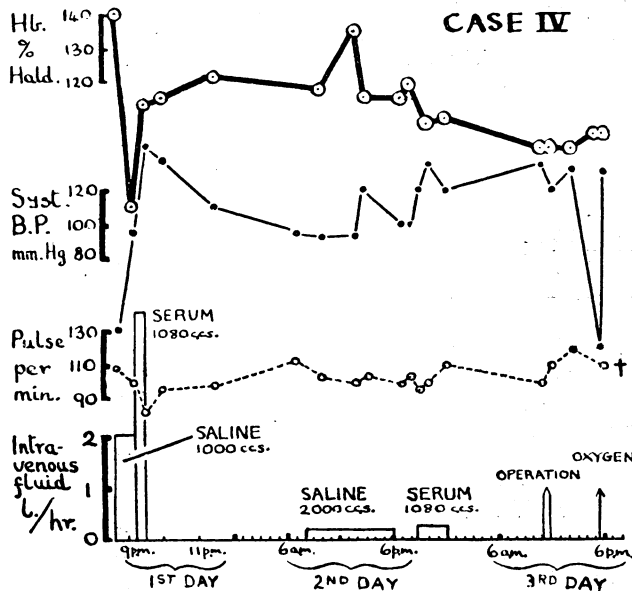


CHART IV.—Case IV (admitted nine hours before the beginning of this chart with a blood pressure of 140 mm. Hg).

raised the blood pressure to a comparatively high level. Next day further serum was given. On the third day the condition of the left foot, which had caused considerable anxiety, was worse: extensive oedema of the thigh had apparently cut off the circulation to the left foot, which was cold and pulseless. Under gas-and-oxygen and ether anaesthesia, incision was made into the left thigh to relieve pressure on the vessels: a feeble pulse was temporarily restored in the posterior tibial artery. Tissue fluid from the thigh contained 1.9 grammes of protein per 100 c.cm. Five hours after the operation the patient suddenly collapsed; although the haemoglobin remained at 105%, the blood pressure fell to 30 mm. Hg. After giving oxygen by B.L.B. mask the pressure rose to 130/82. This restoration of blood pressure was, however, only temporary, and the patient died three hours afterwards. During the last two days there was much vomiting and the abdomen was extremely tense. The urinary output was very low throughout.

Necropsy, by Dr. Keith Simpson, forty-eight hours after death, showed crushed and oedematous muscles of the thigh, with interstitial haemorrhages. There was no bony lesion, no injection, and no gross change in other organs.

On microscopical examination (Dr. Thomas Belt) the muscle showed patchy necrosis, and infiltration with polymorphs. The kidney and other organs were not thus examined.

Discussion

THE RENAL LESION

This consists structurally of severe degenerative changes in the proximal convoluted tubules and, in the more distal part of the nephron, brown pigmented casts of a colour, in unstained preparations, similar to that of blood corpuscles. There are reactive changes round the casts and desquamated epithelium in the medulla (Figs. 1 and 2 on Plate). The matrix of the casts is thought, on histological grounds, to be composed not of red corpuscles but of desquamated epithelial cells. The pigment might therefore

increase noted in serum potassium. An evaluation of the relative importance of muscle injury, renal insufficiency, and possibly adrenal cortical deficiency in the composition of this biochemical picture must await the accumulation of further data.

Oliguria in shocked patients may be due to dehydration, sweating, and the fall in blood pressure (since a pressure below 75 mm. Hg is insufficient to produce urine in the absence of circulating diuretic substances—Winton, 1937). The fall in blood pressure lasted for one and one and a half hours only in Cases I and II. Such oliguria certainly facilitates the precipitation of relatively insoluble material in the tubules both in man (e.g., sulphapyridine calculi) and experimentally (e.g., haemoglobin, Yorke and Nauss, 1911). Another possible cause for anuria in air-raid casualties receiving sulphapyridine is the formation of calculi at the uretero-vesical junction (Sadusk *et al.*, 1940). None of these seemed to be of primary significance in the cases cited.

The part played by transfusion fluids (three of these patients received Group O blood as well as plasma and "serum") must be considered, inasmuch as the pathological changes resemble closely those of the "transfusion kidney." There was no evidence clinically of a transfusion reaction, although such can occur in the absence of one or, rarely, all of such symptoms as rigor, chill, backache, and jaundice. Plasma samples taken at seventeen and a half and forty hours after transfusion showed no increased colour. Further, although in Case I, before blood transfusion, haematuria and albuminuria were absent, the high blood urea and low urinary output suggested impairment of renal function. The case reported by Mayon-White and Solandt in this issue (p. 433), and six other cases of which we have heard, received no blood, but plasma or reconstituted serum only. Perhaps, however, the most potent argument against these being due merely to transfusion reactions is that no such condition has occurred in any of 25 shocked and injured patients without severe muscle crush treated in this hospital by blood or "serum" transfusion.

Treatment

The treatment of this condition so far has been by trial and error. It has been directed primarily to restoring urinary output by means of heat to the loins, by saline dilution of plasma protein (thus increasing the glomerular filtering force), by increasing blood volume with serum and hence blood pressure (thus increasing the glomerular capillary pressure), and by the use of diuretics such as caffeine. Decapsulation should perhaps be tried, as it has been shown to reduce the intrarenal pressure (Winton, 1937). In transfusion kidney this has been done twice with successful results (Bancroft, 1925; Younge, 1936).

The effect of adrenal cortical extract in this condition should also be observed, in view of the raised potassium. The development of electrocardiographic changes in Case I was not associated, however, with any significant alteration in serum potassium (cf. Thomson, 1939). In Case II the changes were similar to those seen in many patients a few minutes before death (Wood, personal communication). However, it is unknown whether changes in the heart muscle manifest electrocardiographically were concerned in the striking terminal collapse.

Prevention by early amputation was thought adequate in Case I; it is evident that thirty-six hours was not early enough. Whether there exists an alternative to immediate amputation we shall learn only by further and fuller investigation of such patients and by careful observation of the effects of treatment, or if the condition can be

reproduced in the laboratory. Investigations which are designed to induce such a condition experimentally are already in progress at this institution.

Summary

Four cases of crush injury to limbs, producing shock, are described in which after recovery due to replacement of circulatory fluid the patients showed oliguria and pigment casts. They died in about one week with nitrogen retention. Necropsy revealed degenerative changes in the proximal convoluted tubules and pigment casts in the more distal part of the nephron. The aetiology and possible lines of treatment are discussed.

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A CASE OF CRUSH INJURY WITH RENAL FAILURE

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When a bomb demolished a hostel at 4 a.m. in January a young male leather-worker of 20, of medium height and good physique, was buried beneath the debris and his left leg was crushed against the side of an iron bedstead by a heavy metal girder. Morphine grain 1/4 and hot drinks had been administered and hot bottles applied to the trunk while attempts were made to extricate the man. When he was first seen at 1.30 p.m. the left leg was still trapped, his mental condition was apathetic, the extremities were cold, and no pulse was palpable at the wrists. He was finally released at 2.15 p.m., ten hours and fifteen minutes after the accident.

On admission to St. Thomas's Hospital the blood pressure was 110 mm. Hg systolic and 70 mm. diastolic, and the pulse rate 136 per minute. The haemoglobin concentration, determined by the Haldane method, was 150% (ear). He was pale and lethargic but not cyanosed, and complained of no pain. The left leg was swollen and