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HEAD INJURIES IN MOTOR-CYCLISTS

WITH SPECIAL REFERENCE TO CRASH HELMETS

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In an earlier paper (Cairns, 1941) attention was called to the use of crash helmets to alleviate the head injuries of motor-cyclists, and 7 cases were reported. We now have records of 106 accidents in which we have been able to examine the crash helmet and, usually, the patient. This material provides further information about head injuries in motor-cyclists, and also enables us to compare the relative values of different types of helmet.

Two main varieties of helmet are in use. In one the outer shell is composed mainly of hard vulcanized rubber; in the other, of compressed wood pulp. Apart from their composition, there are important differences of construction. In the vulcanized type (Fig. 1) the inner suspension system is connected to the outer shell by means of a stout cord at the base

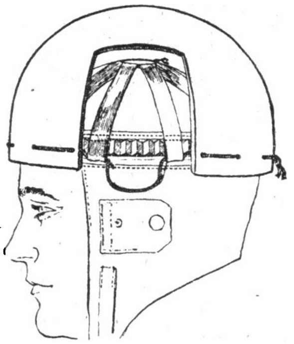

FIG. 1.—Vulcanized rubber helmet.

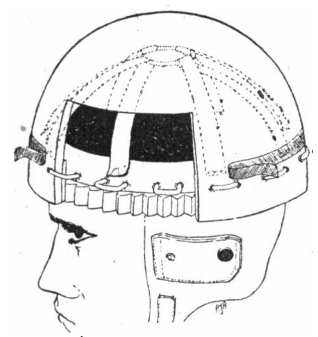

FIG. 2.—Pulp helmet.

of the helmet; if the cord is broken there is nothing to prevent the rider's head from coming into contact with the crown of the outer shell. In the pulp type (Fig. 2) the inner slings are stitched separately into the substance of the outer shell, and the stout cord at the base merely retains the hatband in place.

Material

Our material consists of cases admitted to a Military Hospital for Head Injuries and extramural cases brought to our notice from various sources because of our interest in crash helmets (Table I). Of the hospital cases, those admitted after the acute stage were sent for assessment of their fitness to return to duty, for convalescence, or for special treatment; they were thus a specially selected group. The cases admitted in the acute stage were unselected, except that they did not include the accidents in which the motor-cyclist died before he could be moved to hospital, nor the mild accidents in which the motor-cyclist did not require hospital treatment. The immediately fatal cases and a few of the mild ones are represented in the extramural group—the fatal cases to a disproportionate extent. These have been largely traced through the help of ordnance depots receiving damaged helmets.

TABLE I.—*Head Injuries in Motor-cyclists With and Without a Crash Helmet (Figures for Non-crash-helmet Cases in Black Type)*

	Hospital Cases				Extra-mural Cases	Totals
	Admitted in Acute Stage		Admitted in Subacute or Chronic Stage			
Very mild (no amnesia)	1	**(3)**	3	**(10)**	9	13*
Mild (amnesia $<$ 1 hour)	6	**(6)**	14	**(21)**	7	27*
Moderately severe (amnesia 1–24 hours)	8	**(10)**	23	**(53)**	4	35
Severe (amnesia 1–7 days)	4	**(2)**	7	**(52)**	1	12
Very severe (amnesia $>$ 7 days)	2	**(9)**	3	**(35)**	1	6
Unclassified (duration of amnesia unknown)	—	—	—	**(4)**	3	3
Fatal	1	**(3)**	—	—	9	10
Totals	22	**(33)**	50	**(175)**	34†	106

* Six of the cases in these two groups were so slightly injured as not to require hospital treatment.
† In 2 cases a patient had two separate accidents while wearing the same helmet.

In classifying the cases according to their severity we have used the total duration of amnesia. With certain limitations common to all the subgroups, this provides a rough measure of the intensity of concussion. The severity of head injuries depends on other effects besides concussion—effects such as bruising, infarction, or laceration of parts of the brain, and intracranial haemorrhage or infection—but the clinical state of concussion, as judged by the duration of amnesia, is the only available measure.

In the first six case reports which follow we have attempted to give a fair sample of our material. Cases have been selected from the groups in Table I, so far as possible in proportion to the number of cases in each group. However, we have not taken a case from the "severe" group, since its cases closely resemble those of the "moderately severe" group.

A Very Mild Case

Case 1.—While travelling at high speed Cpl. A., aged 22, hit a rut in the road and was thrown on to his head. The left frontal region of his crash helmet (vulcanized type) showed a large area of abrasion and a fracture, and his triplex goggles were broken into many fragments, but these did not become detached (Fig. 3). He had a cut in his left eyebrow, and his forehead was bruised. He felt dazed for some hours, but did not lose consciousness. He complained of headaches for four days, but remained with his unit. Six months later he was performing full duty efficiently. (Case of Surg. Lieut. B. Robinson, R.N.V.R.)

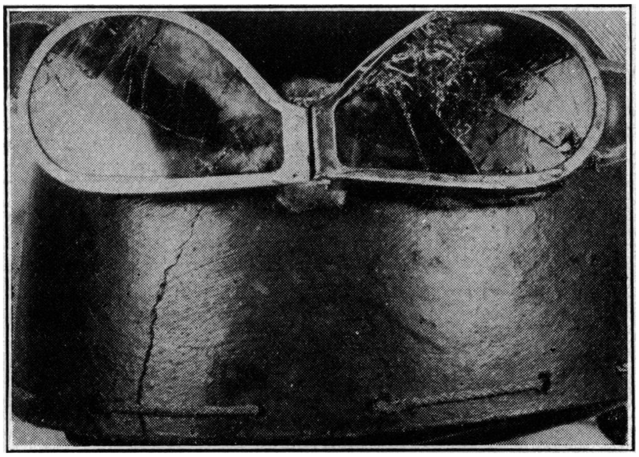

FIG. 3.—Case 1. Broken crash helmet, seen from the left, and goggles, which were worn upside down. The wearer was able to remain with his unit.

A Mild Case

Case 2.—Rifleman B., aged 19, was admitted to hospital after the second of two accidents at an interval of five days. In the first he had had a tyre burst while travelling at 30 to 35 m.p.h., and had gone into a ditch and pitched over the handle-bars. He woke up two minutes later and found himself sitting in the ditch. He was taken back to his unit in a lorry. Five days later, on his next cycle journey, he collided with a lorry which suddenly turned right when he was overtaking it on a main road at 35 m.p.h. This time he was amnesic for 10 minutes, and had bruises on the left side of his forehead, left shoulder, and both knees. Radiographs showed no fractures. After 23 days in hospital he returned to his unit. Although of normal intelligence, he was irresponsible to a degree that probably rendered him unusually prone to accidents.

His crash helmet (pulp type) showed high up in the right frontal region areas covered with a thin layer of earth that were probably produced by the first accident. Lower down in the right frontal region was an extensive area of deeper abrasions and lacerations that was probably caused by the second accident.

Moderately Severe Cases

Case 3.—Cpl. C., aged 24, also had two accidents. In the first, which belonged to the very mild category, he ran into a car that was on the wrong side of the road. His right external malleolus was struck by the bumper, and his handle-bar caught the front-door

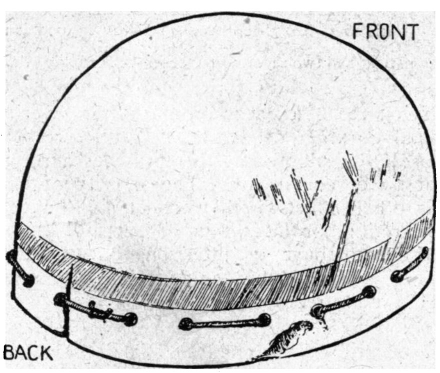

FIG. 4.—Case 3. Fracture at back of helmet (first accident). Indentation and abrasions on right side (second accident).

handle of the car. He was flung off on to the back of his head, but did not lose consciousness. He was unable to stand on his right leg for a quarter of an hour after the accident, but remained at duty and was riding a motor-cycle again next day. His pulp helmet showed a fracture in the occipital region (Fig. 4), which was identified by the patient and his commanding officer as being the result of this accident.

One month later he ran into a flock of sheep. This time his head injury was moderately severe: he was amnesic for two hours and had bleeding from the right ear, with a fracture of the right squamous temporal bone running into the petrous bone. His crash helmet (the same one) showed abrasions on the right side, with a dent at the edge (Fig. 4). He also had bruises of the right shoulder and elbow. He was kept in bed for 17 days, and then, after being up for only half a day, was transferred to a convalescent hospital, where he at once began to have headache and dizziness on exertion and soon became depressed. He was therefore eventually admitted to this hospital. Examination showed no signs other than the fracture of the skull. He was reassured, given graduated exercise, and returned to duty 12 weeks after the second accident.

These cases illustrate the value of crash helmets, and they also raise certain other aspects of accident prevention which, though beyond the scope of this paper, nevertheless deserve more attention than they have received in the past. In Cases 2 and 3 the successive accidents within a short period suggest that these patients might have been more prone to accidents than normal, and that after one accident the liability to accidents is for a time increased.

In Case 3 the treatment given after the second accident was not satisfactory. There is still a tendency to keep patients in bed too long after a mild head injury and then to discharge them from hospital without adequate reassurance or any attempt at physical hardening. In these circumstances unwonted exertion is often followed by headache and dizziness, and the patient, now beyond the control of a medical officer and perhaps at the mercy of over-sympathetic relations, loses confidence in his recovery. His fears aggravate his symptoms and may render him unfit for duty.

Case 4.—Signalman D., aged 28, had a head injury on Nov. 27, 1941. According to another dispatch rider, who was following him, they were travelling at 40 to 45 m.p.h. along an arterial road, when a car in front of them suddenly pulled out, and the patient had to brake so hard that he skidded and fell, striking his head against the kerb. His crash helmet (pulp type, Fig. 5) was penetrated in the

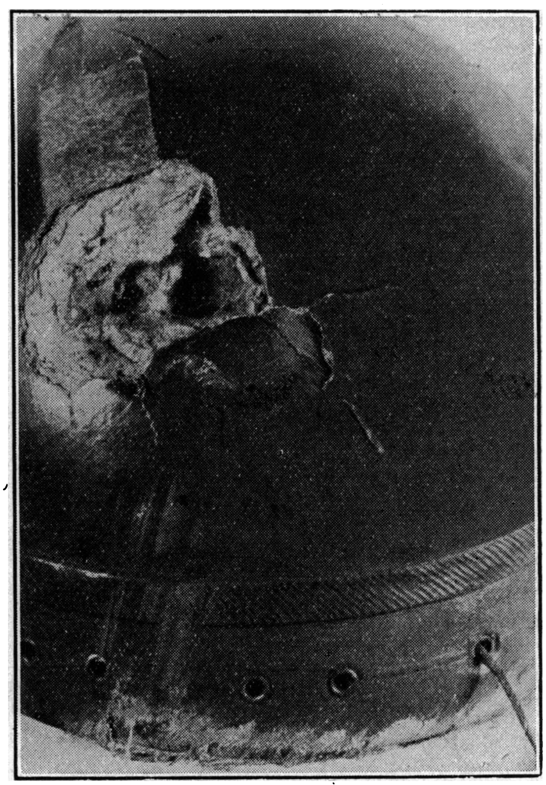

FIG. 5.—Case 4. Penetrating injury and abrasions of pulp helmet.

right frontal region; the surrounding area showed lines of fracture and numerous abrasions, deepest at the anterior edge of the helmet. He had a retrograde amnesia of 3 to 4 minutes and a post-traumatic amnesia of just under 24 hours. Radiographs of the skull showed multiple fissured fractures of the right fronto-parietal region extending on to the greater wing of the sphenoid (Fig. 6), but without any depression. The right fronto-malar suture was also separated. When he was examined two months later no abnormality of the central nervous system could be detected. He did well, and returned to his unit 10 weeks after the accident.

In this case the blow must have been particularly severe, for helmets of this type rarely show gross fractures, and as a rule the skull beneath them is not fractured. It is likely

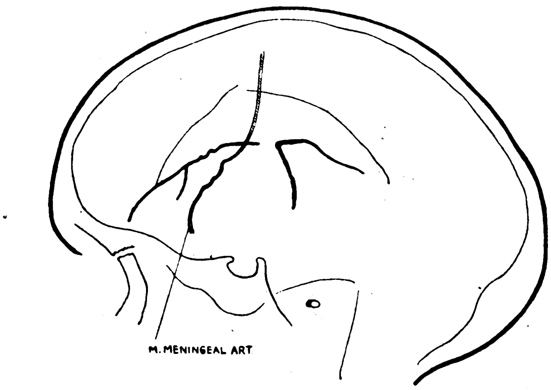

FIG. 6.—Case 4. Multiple fissured fragments of skull in right fronto-parietal region without depression.

that without the protection of a helmet this man would have had a compound depressed fracture of the skull, with penetration of the dura, and severe, perhaps fatal, laceration of the brain.

A Very Severe Case

Case 5.—L'cpl. E., aged 24, ran into the back of an unlit stationary lorry in the middle of the night. He had a small scalp wound above the left ear, with a Y-shaped fracture of the underlying squamous temporal bone, and a superficial graze on the left cheek; he also bled from the right ear. His retrograde amnesia (estimated four months later) was 8 days and his post-traumatic amnesia about 20 days. On admission to hospital he was in coma, with spastic limbs, bilateral ankle clonus, and extensor plantar responses on each side. Within 12 hours he became violently restless, and remained in this state for 8 days; but after hot baths he became quieter. He was, however, still confused for some days, and during this time he had an incomplete and temporary right facial palsy of the peripheral type. The signs of organic neurological damage cleared up completely, but he still complained of headaches on exertion and gross impairment of memory. Attempts at active physical and psychotherapeutic rehabilitation failed, and he was invalided from the Army 4½ months after the accident.

His crash helmet (pulp type) showed a fracture with slight depression at the left lateral edge. Beneath this fracture the rim of the fibre hatband was broken, and the break corresponded with the scalp wound above the left ear.

This patient had a severe brain injury, with fracture of the base of the skull, which might have been fatal if he had not been to a considerable extent protected by the crash helmet from the full violence of the blow. Eventually he made a good recovery; but after such a prolonged period of post-traumatic coma and amnesia the capacity for satisfactory work may be slow to return, and in this case recovery was complicated by the fact that before the accident his adjustment to Army life had not been altogether satisfactory.

Fatal Cases

Case 6.—L'cpl. F., aged 27, came over the crest of a hill to find an oncoming car turning right towards the entrance of a station. His cycle struck the offside front wheel of the car, and he was thrown a distance of 40 feet, striking his head against cobbles (Fig. 7). His crash helmet (vulcanized type) had an

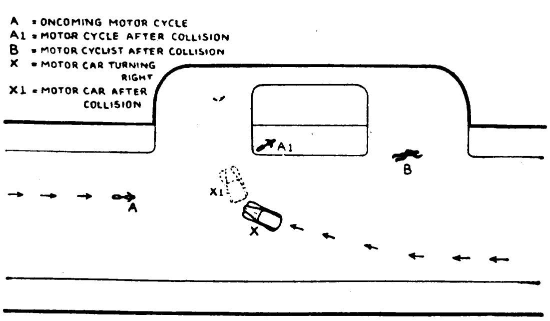

FIG. 7.—Case 6. Diagram of accident.

extensive fracture on the left side (Fig. 8), and there was an extensive fracture also in the left temporo-parietal region of the skull, spreading into the middle fossa. The patient never recovered consciousness, and died 51 hours after the accident. Before death he had right hemiparesis and rapid bubbly breathing. Necropsy showed, in addition to the skull fracture, extensive laceration and

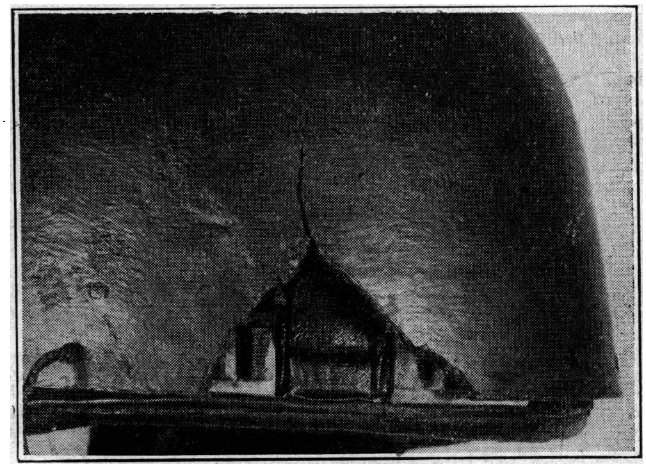

FIG. 8.—Case 6. Fracture of vulcanized helmet.

haemorrhage of the left hemisphere beneath the site of the blow, together with a small amount of extradural clot. (From notes supplied by Brig. Hedley Whyte, D.S.O.)

In this case a less brittle and more strongly buffered helmet, protecting a wider area of the temporal region, might have prevented the fatal brain damage. Violent blows in the unprotected region of the external ear and mastoid process seem to be very liable to produce death.

In the fatal cases which we have examined death was not always due to head injury. In the following case—the only fatal case among those admitted to our hospital—the crash helmet was effective in preventing brain damage, but the patient died from bronchopneumonia secondary to injury of the thorax.

Case 7.—Travelling fast in daylight, with his head bent forward, Pte. G., aged 29, crashed into the back of a stationary lorry. Witnesses say he bounced back about six feet and landed sitting on his motor-cycle, then slowly keeled over sideways. A few hours later he was admitted to hospital in a comatose restless condition and showing signs of traumatic asphyxia. Temperature 103°; pulse rate 150; respiration rate 40. His crash helmet (pulp type, Fig. 9) showed

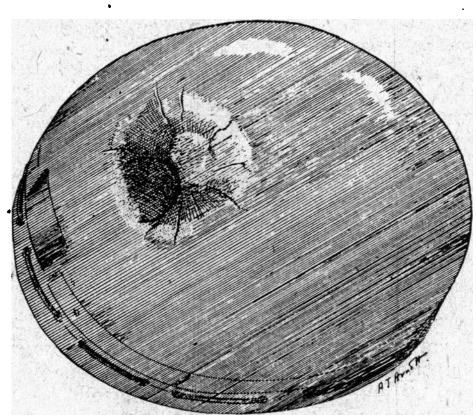

FIG. 9.—Case 7. Severe indentation of pulp helmet.

a large dent high up in the frontal region, with an eccentric deep semicircular mark which suggested that he had run into a piece of piping projecting from the back of the lorry, though it is stated that he hit the tailboard. There was also a deep transverse groove running across the posterior surface of the helmet. No signs of a lesion could be found in the scalp or skull. He had a bruise on the front of his sternum, fractures of upper thoracic vertebrae, and compound fractures of the left second and fourth metacarpals. Lumbar puncture (10 hours after injury) showed lightly blood-stained fluid under an initial pressure of 140 mm. H_2O, with a protein content of 100 mg. per 100 c.cm. and 7,200 red cells per c.mm. During the next three days he became less deeply unconscious; but his breathing remained rapid and stridorous, and he gradually developed signs of bilateral bronchopneumonia, with a small pneumothorax on the right side, widening of the upper mediastinal shadow, disappearance of the heart sounds, and a persistently rapid pulse with gallop rhythm. He died four days after the accident.

Necropsy (carried out by Drs. Robb-Smith and Dorothy Russell) showed a fracture of the sternum beneath the bruise on the chest wall. There were considerable extravasation of blood in the upper mediastinum, slight bruising of the wall of the left ventricle of the heart, and bronchopneumonia. Neither the scalp nor the skull showed any sign of damage, and the only lesion found on the surface of the brain was a small amount of subpial haemorrhage along the medial sagittal border of each cerebral hemisphere. Coronal sections showed numerous petechial haemorrhages, with softening of the white matter, symmetrically scattered through both temporal lobes, linear haemorrhages in both fusiform gyri, and a few perivascular haemorrhages in the left frontal lobe. These were not sufficient to cause death, and on microscopical examination there were no signs of fat embolism. There was some bruising of the dura just above the foramen magnum and of the muscles of the neck. The spinal column showed a fracture-dislocation between the third and fourth thoracic vertebrae and a crush fracture of the body of the sixth thoracic vertebra, without injury to the spinal cord.

In this case there was undoubtedly a very severe blow to the head, and the crash helmet appears to have been most effective in preventing damage to the brain and skull; but it was not able to absorb all the energy of the blow on the head, and some of the force was transmitted to the spinal column. The primary cause of death was bronchopneumonia and mediastinal haemorrhage, due to a second blow on the chest and possibly also to the spinal injury.

Marks on the Helmet

From the marks on the outer shells of the helmets it is possible to deduce the positions of the blows and to some extent their severity. On the vulcanized type of helmet a serious blow generally causes a triradiate Y-shaped fracture of the outer shell, with its junction near the centre of the blow and the vertical limb usually extending to the edge of the helmet. With blows of still greater severity the upper arms of the Y may curve round and reach the edge, so that portions of the helmet become detached (Fig. 10).

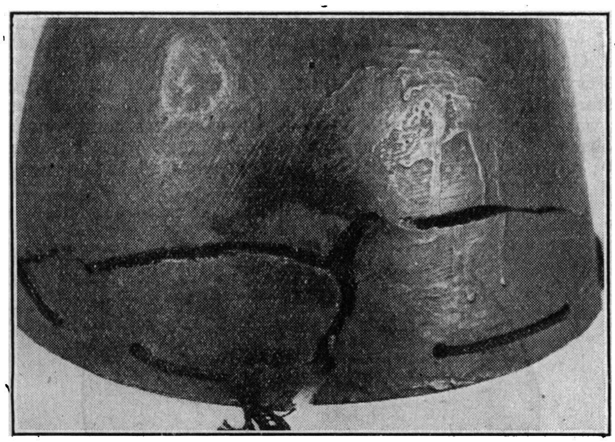

FIG. 10.—Vulcanized rubber helmet showing typical severe blow in the occipital region. The wearer was able to continue at duty.

The imprint of the object causing the blow is generally found near the junction of the Y. If the blow is due to the road inconspicuous groups of small pits, the imprints of the sharp corners of the road metal, are found at this point. The pits often have small tails to them, due to a small amount of "slip" between road and helmet. The pits may be easily overlooked, as they appear insignificant in comparison with the long and deep abrasions produced when the helmet is sliding along the surface of the road. And it must often happen that the pits due to the original blow are completely obliterated by abrasion marks due to subsequent sliding. In less serious blows the inconspicuous pits may occur without any fracture.

A blow by another vehicle usually causes a fracture. Near the centre of the fracture lines the paint may show an extremely faint polish at the summits of its irregularities, akin to the polish which occurs on the thicker parts of a starched collar from the pressure of the iron (Fig. 10). Sometimes the impact of another vehicle produces a smooth area denuded of paint.

The pulp type of helmet, being less brittle, seldom shows gross fractures; instead, an indented slightly softened area is produced by the blow. In this area there is slight wrinkling of the material, with little tendency for the wrinkles to run to the free edge (Fig. 9). Impact with the road usually causes small jagged tears of the layer of gossamer covering the helmet. The only clear evidence of impact with another vehicle is obtained in cases such as Case 7, in which an imprint of some geometric shape is seen in the helmet. No imprints of geometric shapes are found in the vulcanized helmets, presumably because the material breaks before it is sufficiently deformed to leave a permanent impression.

Multiple Blows

In 40% of 81 cases the helmet showed marks of more than one blow. In 2 cases the history and the character of the indentation in the helmet suggested that the patient struck two objects at once, one in the front part of the crown of the helmet and the other in the occipital region. In another case the helmet was crushed by the wheel of a lorry and fractured on both sides. In the remaining cases it is likely that the patients received successive blows against widely different areas of the helmet. There were indications in the marks that one blow was more severe than the others.

Case 8.—Pte. H., aged 27, struck the back of a lorry in daylight while riding his motor-cycle. He had a scalp wound in the forehead, a fractured frontal sinus, amnesia for two days, and double vision for two to three weeks. His crash helmet (vulcanized type) showed an irregular defect in the mid-frontal region, and, at the apex of this defect, depression of one fragment of the shell. In the right postero-lateral region the shell showed a second fracture, which was surrounded by areas of abrasion.

In this case there were clearly two blows—one on the front and one on the back of the helmet. Possibly the first blow was caused by the patient's head striking the lorry, and the second by his subsequent fall to the ground. That the main blow was on the forehead is shown by the severity of the damage to the front part of the helmet and by the fact that the damage to scalp and skull was beneath that area.

Evidence for multiple blows is also obtained from those cases in which there are fracture of the jaws and damage to the skull in some part other than the frontal and temporal regions.

Case 9.—Lieut. I., aged 24, crashed into a lorry which suddenly turned right into a side road. On admission to hospital two hours later he showed a simple fracture of the lower end of the left fibula, a comminuted fracture of the symphysis of the mandible, a fracture of the left condylar process of the mandible, and a fracture of the adjacent tympanic plate. There was no other fracture of the skull. His crash helmet was unmarked in the front, but showed a line of abrasions and a fracture in the left occipital region, with some general depression of the left occipital part of the helmet. The patient was amnesic for 7 days, and during the first part of this period was in a very confused state. He subsequently made a good recovery.

In this case there were obviously two blows—one on the face and one in the occipital region. Most of these cases of multiple blows appear to have occurred when the rider collided with a vehicle, such as a lorry or a taxi, and the first blow was probably due to striking the vehicle, the second to striking the ground. But in one fatal case of which we have read the report there is a circumstantial account that the rider fell and struck a fallen tree-trunk, then bounced up into the air, fell, and struck his head again.

Our observations confirm the experience of Rowbotham (1941) that "in road accidents in particular the head may be struck more than once." In the initial examination of a case of head injury, therefore, the medical officer should not be satisfied with finding one scalp wound, but should search the head for evidence of another. In a case which came to our notice neglect of this rule resulted in death from meningeal infection through an untreated wound of the hairy part of the scalp.

The Site of the Blow

The site of the marks on the helmet and the damage to the underlying scalp or skull showed a close correspondence. In 30% of our cases we could not establish a precise relationship —usually because there was no mark on the scalp or skull (e.g., Case 7), but sometimes because the marks on the head, though close to the marks on the helmet, were not directly below them. In only 5% was there a définite variance between the site of the marks on the helmet and those on the head. In the remainder—i.e., in 93% of those in which requisite data were available—correspondence was precise.

The helmet thus provides a permanent record of the blow, and this is useful in patients who come under observation after their bruises and lacerations have healed. In some of our cases it has led to detection of fractures of the skull which had been overlooked at the first radiographic examination.

When the site of the main blow is plotted diagrammatically it is seen that blows on the frontal quadrant are almost as frequent as all the others put together (Fig. 11 and Table II).

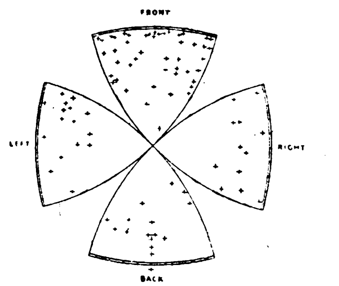

FIG. 11.—Diagram of site of main blow in 91 cases.

Blows on the front half of the helmet are over twice as frequent as blows on the back half. The majority are at or fairly near the edge of the helmet (the average height of blows is 4.5 cm. above the brim), and blows on the crown, an area approximately equal to that of a quadrant, are very rare: there were only 3 cases in which the blow was primarily on the crown. The

TABLE II.—*Effects of the Main Blow on Skull and Brain in Relation to Site of Injury**

Site of Injury	Total No. of Cases	Cases with Skull Fracture	Deaths attributable to Brain Injury
Frontal ..	47	16	3
Lateral	28	17	3
Occipital ..	21	3	—

case of the motor-cyclist is quite different from that of the equestrian, who starts his fall from a considerable height and has time enough to perform the rotation necessary for a fall on to the crown of his head. The motor-cyclist rides close to the ground, and in an accident usually falls from his machine in a forward, or lateral and forward, direction without enough height to perform the necessary rotation.

These observations show the importance in design of providing particularly good protection at and immediately above the edge of the helmet, especially at the front, where blows are two to three times as common as in any other part.

Effects of Blows in Different Regions

The outstanding feature of Table II is the mildness of the effects of blows in the occipital region in comparison with those on the frontal and lateral regions. It may be that in motor-cyclists a blow in the occipital region occurs only after the body of the motor-cyclist has almost come to rest; and that this is the explanation of the slightness of occipital injuries. Motor-cyclists probably do not turn somersaults in mid-air unless the initial violence is taken on some other part of the body before they turn over on to the occiput. Furthermore, the occipital region is more completely protected by the helmet, and below that by the neck muscles, than are other parts of the cranium.

Blows on the frontal and lateral regions are much more dangerous, and the figures of deaths and of fractures suggest that the lateral blow is the more dangerous of the two. The lateral regions are not well covered by the present designs of helmet, and the main effect of the blow may fall on the cranium below the level of the helmet. Similarly, the lower part of the frontal region is exposed to blows, particularly when motor-cyclists wear a helmet which is on the small side: in them the main violence may be applied to the unshielded supra-orbital ridge.

Of the 3 cases in which the blow was on the crown of the helmet one was the result of a mild glancing blow that produced only momentary amnesia. In the other two the blow was severe, and was associated with a crush fracture of the spine. One of these has been already described (Case 7); the other is as follows:

Case 10.—Driver J., aged 20, was following a van at 40 m.p.h. when it suddenly slowed and swung into the middle of the road in preparation for turning left. His cycle struck the near-side mud-guard of the now almost stationary van, and he was flung over the handle-bars. He was rendered momentarily unconscious, and had an abrasion on the bridge of his nose, pain in the back, and fractures of metacarpal bones of both hands. No signs developed in the central nervous system, but radiographs showed a crush fracture of the seventh thoracic vertebra. He returned to duty four months after the accident. (Major P. Clarkson's case.) His crash helmet (pulp type) showed numerous pitted and linear abrasions on the crown in an area 20 by 9 cm., extending forwards to the upper part of the frontal region. The patient's story was that his head had struck the back of the van; but this is unlikely, for in one of the abrasions was a fragment which was identified as road metal. In the inner sling of the helmet the stitches holding the two anterior loops to the outer shell were completely torn through.

It is significant that this case and Case 7 are the only two cases in the series in which a fracture of the vertebral column was found. However, the incidence of spinal column and spinal cord injury in motor-cycle accidents cannot be properly assessed without including a study of those patients who die soon after the accident and before they reach hospital; and in these cases thorough post-mortem examination is rarely made. In a series of 46 fatal motor-cycle accidents studied from the records of the Claims Section of one of the Army Commands there were three cases of instantaneous death ascribed, without necropsy, to broken neck. While the evidence is thus not very satisfactory, it does suggest that spinal injury is relatively uncommon after motor-cycle accidents, but that it should be looked for especially in those cases in which the blow is on the top of the head.

Absence of Marks on the Helmet

The value of head protection has been criticized on the grounds that brain damage is produced by violence applied to parts other than the head and transmitted to the base of the skull through the facial bones or the spinal column. In our series there were only 9 cases in which the helmet shell did not bear any marks of a blow, though the patient was regarded as a case of head injury.

Of these cases 5 proved to have had a head injury. In three of them there was laceration of one eyebrow below the crash helmet, which was too small for its wearer. In one case there was evidence of a blow on the leather flap covering the left ear. In the other case the lining of the helmet was broken and it is presumed that there was a blow on the head: this was one of our early cases, seen at a time when we were not yet expert at recognizing marks on the shell.

In 1 case the nasal bones were fractured and the patient did not become unconscious. In 2 cases the patient had a fracture of a limb bone, amnesia of short duration, and no evidence of a blow on the head or face. In these two cases it is possible that there was no brain injury, for amnesia may occur in uncomplicated cases of fracture of the femur in which there is no head injury. In one such case it was possible to demonstrate that, although the patient appeared to respond rationally during the stage of primary shock, he subsequently had amnesia for the greater part of the period. Another possible explanation for these cases is that there may have been a blow in the region of the foramen magnum transmitted through the vertebral column; but in the absence of any evidence of vertebral injury this seems unlikely.

In the ninth case, described as one of concussion, closer inquiry, after we had failed to find any marks of injury to the helmet, revealed that the man had not been concussed but had become amnesic from fright.

Case 11.—Gunner K., aged 27, was admitted to our hospital some two months after a motor-cycle accident suffering from the after-

* The number of cases was not large enough to enable us to estimate the relationship of the site of the blow to the duration of amnesia.

effects of head injury. The story obtained by the medical officer was that the man had collided with a car and that his retrograde amnesia was 1 to 2 seconds and his post-traumatic amnesia 6 hours. His complaints were of fairly continuous headaches, dizziness, and a feeling of weakness on attempting to do physical training. Examination showed no signs in the central nervous system. As his crash helmet bore no marks and he was obviously a rather nervous individual, his history was gone into more closely. Inquiry disclosed that there was in fact no retrograde amnesia and that his post-traumatic amnesia had not begun until half an hour after the injury, and had lasted until he was awakened 5½ hours later by a medical officer, who told him that he had had an accident. With the patient under pentothal, Capt. P. W. Nathan was later able to obtain a connected story of the whole period of amnesia and also fresh information about the man's anxieties and fears, which provided an adequate explanation of his symptoms.

It is probable that this case would have remained under a false label if absence of marks on the crash helmet had not led to closer inquiry.

Thus in the 106 accidents we are considering there is evidence of a blow on the head in all but 4. Of these four, one was a case of broken nose and another was a case of amnesia from fright. In the remaining two it is possible that slight brain injury may have resulted from violence applied to the base of the skull through the spinal column, though it is more likely that the brief amnesia which occurred was due to shock associated with fracture of a long bone. These observations do not disprove the contention that brain injury may result from injury to the face or spinal column, but they do establish the fact that in motor-cyclists brain injury is almost invariably associated with a blow on the head, protection against which can be provided by a properly fitting crash helmet.

Damage to the Helmet Lining

In considering the information which can be obtained from knowledge of the site of the blow we have dwelt of necessity on the damage to the outer shell, but it is important to recognize that the protective value of a helmet should rest to a great extent on its inner lining. With blows on the crown of the helmet the slings should absorb the energy of the blows, but they cease to do this as soon as the rider's head comes into contact with the outer shell. Owing to the rarity of blows on the crown, these slings are rarely brought into play; for in pulp helmets, in which it is to some extent possible to judge the strain placed upon them, the slings were broken in only two cases.

Against frontal, lateral, and occipital blows the hatband offers protection in proportion to its power to act as a buffer. This part of the inner lining could be altered with advantage, especially in the frontal region, where blows are most common.

The presence of a cord on the outer surface of the shell has been criticized by Gardner (1941) on the grounds that friction of the cords increases the deceleration of the head, thus rendering the effects of the blow more severe. We agree that the severity of the injury depends largely on the rate of deceleration, and that this rate can be reduced by sliding. Gardner suggested that the presence of the cord increased materially the risk of spinal injury. In our series of 104 cases there were only 2 cases of fractured spine, in one of which the blow was on the crown of the helmet and the cord was intact. We consider that the cord has proved to be an unnecessary feature of the design, and are thus in general agreement with Gardner. But we do not think that it is important in promoting deceleration, because the coefficient of friction between the surface of the helmet and the road, or whatever object the helmet strikes, is not altered adversely by the presence of the cord.

Our main objection to the cord concerns its use in the older type of vulcanized helmets as the connecting link between the inner lining and the shell (Fig. 1). In our series the outer cord was broken in 30 of the 52 vulcanized helmets and in only 9 of the 52 pulp helmets. This difference is significant, and is due to the fact that in the vulcanized type the cord is stretched when the helmet is struck and forced further on to the head; whereas in the pulp type the cord is not stretched as a result of the blow, since each sling, being stitched to the shell separately, is independent of the cord. As the helmet moves along the surface struck, the friction is usually enough to break the stretched cord of the vulcanized helmet, but does not suffice as a rule to break the unstretched cord of the pulp helmet. These effects may be compared with the well-known observation that when string is tightly stretched it can be much more easily cut with a pocket-knife than when it is not under tension.

The Theory of the Mode of Action of Crash Helmets

The chief functions of a crash helmet are two: (1) prevention of local injury in the region of the blow; and (2) prevention of effects remote from the region of the blow—viz., concussion, so-called contrecoup injury, etc.

Prevention of Local Injury.—The shell of the helmet acts partly by spreading the blow over a wider area, thereby diminishing its intensity at any one point. It is in this way, for example, that the helmet protects the scalp and skull from the pointed parts of the object struck, such as the sharp fragments of road metal projecting from the surface of the road. Hence, even by the action of the shell alone, some diminution in the number of fractures of the skull should be expected. In addition, some of the fractures should be prevented from becoming depressed, thereby reducing the liability to dural penetration and damage to the underlying brain. Since, owing to the stiffness of the shell, bending of the skull by the force of the blow is also lessened, there should be less contusion of the brain at the site of impact. The so-called "coup" lesion is, in our view, due to the bending of the skull under the blow.

The shell of the helmet also functions by "lengthening the blow"—that is, by spreading it out over a longer interval of time, so that it is not so intense at any particular instant. However produced, lengthening reduces not only the local injury but all other effects of the blow. The shell accomplishes this by sliding over objects for some time instead of stopping more abruptly, as the unprotected head would do owing to its greater coefficient of friction. But the main way in which the blow is spread over a longer time is by means of the buffering action of the slings and hatband. The blow lasts during all the time that the slings are being stretched or the hatband is being compressed, instead of only during the time taken to deform the scalp and skull. It is consequently reduced in intensity, and the local damage to scalp, skull, and brain is less severe. These parts of the existing types of helmet could be improved.

The blow is also lengthened to some extent by the rotation of the helmet relative to the head.

Prevention of the Remote Effects of the Blow.—The blow produces a change in the velocity of the head which may be either an acceleration or a retardation (Denny-Brown and Ritchie Russell, 1941). Calculation shows, however, that the change in the linear (or straight-line) velocity of the head produces only insignificant effects. The main effects are produced by a change in rotational velocity. As a rule the blow imparts a sudden rotation to the head. This is the cause of all gross bruises or lacerations of the cortex remote from the site of the blow. All the available evidence points to its being also the cause of the concussion. Anything which reduces the force of the blow will tend, other things being equal, to diminish the sudden rotation and its attendant lesions. Spreading the blow over a larger area is not effective from this point of view, since the total force is unaltered. But spreading it over a longer interval of time is to some extent effective, since the total force at any instant is reduced. Hence, owing to the sliding action of the shell and the buffering action of the slings and hatband, the helmet is effective in reducing the so-called contrecoup injuries and concussion.

Observations on the Effects of Crash Helmets

There are three groups of motor-cyclists to be considered: (1) those who die on the road before they can be moved to hospital—approximately 20% of 46 fatalities in one Army Command whose records we examined; (2) those who are

Table III.—*Influence of the Crash Helmet on the Incidence of Fracture of Skull and Duration of Amnesia (Hospital Cases only)*

	Acute Cases		Subacute and Chronic Cases	
	No Crash Helmet	Crash Helmet	No Crash Helmet	Crash Helmet
Fracture of Skull	63%	32%	39%	40%
Amnesia:				
Nil	3	1	10	3
< 1 hour	6	6	21	14
1–24 hours	10	8	53	23
1–7 days	2	4	52	7
> 7 days	9	2	35	3
Unclassified	3	1*	4	—
Totals	33	22	175	50

* Death due to causes other than head injury.

admitted to hospital; and (3) those whose injury is so slight that the motor-cyclist is not taken to, or is not detained in, hospital. Our information on the first and third groups is meagre. In the hospital cases there is a very significant difference between the motor-cyclists who were wearing crash helmets and those who were not (Table III).

Fractures.—Fractures of the skull are less frequent: as shown in Table III, of the patients admitted to our hospital in the acute stage only 32% of those wearing crash helmets had a fracture of the skull, as compared with 63% of those not wearing crash helmets. That the subacute and chronic cases do not confirm this finding is probably due, at least in part, to the fact that in those who wore a crash helmet our ability to find fractures long after the injury was considerably increased by knowing, from the marks on the helmet, where to look for them by means of further radiographic examinations.

Such fractures as do occur when a crash helmet is worn are probably much less severe than they would otherwise have been; for instance, the fracture may be fissured instead of depressed, as is perhaps exemplified in Case 4. In this hospital's series of injuries involving the frontal and ethmoidal sinuses, which have been collected by Major C. A. Calvert, there are 34 cases in which it is known whether or not a crash helmet was worn (Table IV). Among those who did not wear a crash

TABLE IV.—*Damage resulting from Fractures of Frontal and Ethmoidal Sinuses in Motor-cyclists*

	Without Crash Helmet	With Crash Helmet
Anosmia	14	1
Rhinorrhoea	7	—
Meningitis or brain abscess	2	—
Aerocele	1	—
Injury to carotid artery	2	—
Injury to optic nerve or chiasm	4	—
Displacement of eyeball or severe oculomotor paralysis	4	—
Disposal:		
Duty	12	8
Permanently unfit for military service	9	1*
Died	3	—
Under treatment	—	1
Totals	24	10

* Owing to malunited fracture of lower limb.

helmet severe fractures of the inner table of the skull are common: as the table shows, there are examples of cerebrospinal rhinorrhoea, intracranial aerocele, meningitis, brain abscess, aneurysm of the internal carotid artery, lesions of the optic nerve or chiasm, and displacement of the orbit—in fact, most of the severe complications of extensively depressed fractures involving the frontal and ethmoidal sinuses. The patients who wore crash helmets were all free from these complications, with a corresponding improvement in the after-results. It is true that the chances of a patient being sent from a distance to this hospital are greater if he has one or more of the complications mentioned above than if he has none of them; but there is no selection as between those who have worn crash helmets and those who have not, and the most reasonable explanation of these figures is that the crash helmet is effective in preventing fractures of the frontal sinus from becoming depressed, from spreading widely, and from tearing the overlying dura, events which comprise one of the most important causes of morbidity and mortality among injured motor-cyclists. But to exercise this effect the helmet must come well down over the forehead, and, in view of the number of motor-cyclists who wear helmets which are too small for them, it is rather surprising that the results shown in Table III appear to be so uniformly favourable to the crash helmet.

Concussion.—In those patients who were wearing crash helmets, concussion, as measured by the duration of amnesia, was milder than in those who were not. As Table III shows, there is a significant reduction in the length of the amnesia: taking the acute, subacute, and chronic cases together, among the 208 cases in which no crash helmet was worn there were 44 (22%) with an amnesia of more than 7 days' duration; while among 72 cases in which a crash helmet was worn there were only 5 (7%) with an amnesia of more than 7 days.

Hence crash helmets cause a significant change in the percentage of fractures and long amnesias in those patients who come into hospital. The severity of injuries in a hospital population is not an easy thing to alter, and the fact that a detectable alteration has occurred implies that crash helmets have had a profound effect on the severity of injuries on the road. Unfortunately, it is not possible to give a mathematical "proof" that this alteration in severity has been in the direction of making the injuries milder, but common sense tells one that in most directions the change must have been for the better.

Some indirect quantitative evidence as to the effectiveness of crash helmets comes from a comparison between the two types of helmet. In the patients whom we have observed in hospital the distribution of the two types of helmet has been approximately equal (37 pulp and 35 vulcanized), but throughout the Army in this country during the period under investigation the issue of pulp and vulcanized helmets has been in the proportion of 2:1. The reasonable explanation of this is that half the accidents in wearers of pulp helmets were made so much milder than they would have been if a vulcanized helmet had been worn that the patient never came into hospital. The alternative explanation, that the pulp helmet made the accident so severe that half its wearers died before they got to our hospital, is rejected on the grounds that (*a*) the pulp helmet is the better helmet of the two (see below), and (*b*) such an enormous increase in the death rate would be easily seen from the figures of deaths to all motor-cyclists from all causes; these have, in fact, shown a decline since the introduction of crash helmets. No deductions can be made from this decline alone, since it is influenced by so many factors.

The estimate that the pulp helmet alleviates one-half of the injuries to such an extent that the dispatch rider does not require to go to hospital is a minimum estimate, based on the assumption that the vulcanized helmet had no effect in increasing or alleviating injury. But if, as we have reason to believe, the vulcanized helmet is of considerable use, this is an under-estimate of the effectiveness of crash helmets.

Using the minimum figure—that the pulp helmet saved one-half of its wearers from hospital—we can return to the data of Table III, which show that of the 72 hospital patients of all kinds wearing a crash helmet only 16 (22%) had an amnesia of one day or more, whereas of the 208 hospital patients not wearing a crash helmet 98 (47%) had an amnesia of one day or more. If we combine these facts with the supposition that there were at least another 37 pulp-crash-helmet accidents in which the riders never came to hospital because their injuries were so much reduced by their helmets, we obtain the result that the severe amnesias in 100 crash-helmet accidents number only about 15, at most, whereas in 100 non-crash-helmet accidents they number 47. We therefore deduce that the present helmets have reduced the severe amnesias to at least one-third of what they would have been.

Comparison of Types of Helmet

For a direct comparison of the two types we can use our figures for the total number of crash-helmet cases, which include many that did not come to this hospital and in which, since information was sought from all sources, there is a high proportion of fatalities. There were 52 of each type. Table V shows that in the vulcanized helmet group the outer shell is broken with much greater frequency, and skull fracture in cases coming into hospital is nearly twice as common. On the basis of these figures and those of the general distribution

TABLE V.—*Comparison of the Two Types of Helmet*

Type of Helmet	Total	Fracture of Helmet Shell	Fracture of Skull	Deaths	Remarks
Vulcanized	52	43	23	5	All due to head injury
Pulp	52	18	12	5	4 died of injuries to parts other than head

of the two types of helmet we may conclude that as regards prevention of fractures of the skull the pulp helmet is about four times as good as the vulcanized. If the vulcanized helmet were of no use in preventing fractures, then the pulp helmet would reduce fractures to one-quarter of their former incidence.

There is no significant difference in the duration of amnesias in the two groups of cases. But for this comparison our figures are rather small. However, if we suppose that the serious amnesias in the two groups are in fact equal, then, since there are twice as many pulp helmets as vulcanized helmets in use, the serious amnesias per accident are twice as great in the vulcanized group as in the other.

Conclusions

In all, 106 examples of head injury in motor-cyclists wearing crash helmets have been examined.

The site of the blow on the helmet and the injury to the underlying scalp and skull correspond.

Over 50% of the blows are on the front of the helmet. The least common site of injury is the crown of the helmet.

Blows on the occipital region are least dangerous and those on the temporal region most dangerous to life. Blows on the crown may be associated with crush fractures of the vertebrae.

In 40% of the cases the head receives more than one blow.

In motor-cyclists it is very rare that brain injury results from a blow limited to the face.

The crash helmet is effective in diminishing local damage to the brain and its coverings at the site of impact, and it tends to lower the incidence of cases of prolonged amnesia.

Though our figures are rather small they suggest: (*a*) that the incidence of fractures of the skull is quartered by the better (pulp) type of helmet: the severity of those that do occur is less; (*b*) the incidence of prolonged amnesia (one day or more) is only one-third of that in accidents in which no crash helmet is worn; (*c*) in non-lethal accidents the pulp crash helmet so alleviates the injury that one-half of the dispatch riders who without its protection would have to go to hospital do not need to do so.

Of the two types of crash helmet in common use the pulp helmet is superior to the vulcanized rubber helmet.

Further improvements in the design of helmets offer a profitable field of preventive medicine.

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A practical example of rehabilitation was mentioned at the sixty-third annual meeting of the Mental After-Care Association. The superintendent of one of the homes for convalescent male patients arranged with a local factory doing war work of much importance, first to train him in some semi-skilled processes with light and portable material, and then to send such material to the home in order that he might teach the patients to work upon it. Although this experiment was started only towards the close of last year, already the finished work sent back to the factory by the patients has greatly exceeded the firm's expectations alike in its accuracy and in the speed with which it has been done. Even more gratifying is the beneficial effect apparent in the patients. Their conversation at table is no longer about nerves and insomnia, and the reflection that they are taking some active part in the national effort is a great stimulus to their conversation, self-respect, and mental health. Col. Henry Yellowlees, chairman of the association, said at the meeting that the original object with which the association was founded was curative work, and the council had aimed at turning ex-patients into useful citizens, constructing a bridge over which the patients might pass from the restraints and seclusion of mental treatment to the freedom of responsible working life. Mr. R. Sargood, chairman of the Mental Hospitals Committee of the L.C.C., said that his council had no intention of doing this work itself, but was content to leave it in the hands of the association. The Bishop of London also supported the objects of the association (of which 13 bishops are vice-presidents), and spoke of the function of the pastoral office in helping people to regain mental health. During last year the association dealt with 2,500 patients, of whom over 1,000 were sent to the homes.

THE DIET IN DIABETES

BY

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Recent correspondence in the *Journal* has shown that some physicians are doubtful about the necessity for accurate dietetic control in the treatment of diabetes; it follows that they must be prepared to doubt the importance of maintaining the diabetic's blood sugar at a level near to normal. To all those who share this scepticism and to all those who are interested in the study of their less docile diabetic patients I offer, in full consciousness of all that I have still to learn, this short summary of my experience, conclusions, and practice.

Early in my experience as a physician, nearly 20 years ago, I found that it was possible to maintain excellent health and vigour in those rebellious severe diabetics who refused to follow any regulated diet, no matter how liberal it might be. Some of them made no secret of their refusal to follow directions, but others tried (often successfully) to pass themselves off on their doctor as model patients. About 12 years ago I began to approve of the abandonment of strict dietetic control for those patients who found that they could succeed in maintaining a sugar-free urine only at the cost of hypoglycaemic attacks. Finally, during the last eight years I have never (except in the case of diabetes of very recent onset) advised a diabetic patient to eat a regulated diet, and I have often transferred a conscientious but worried patient from controlled to uncontrolled diet without deterioration in his condition. At the present time none of my diabetic patients are on a controlled diet.

General Principles of Treatment

My experience has been that in all cases of diabetes seen by me the maximum attainable degree of health and vigour could be maintained despite a persistently high blood sugar. The chief aim of diabetic treatment seems therefore to be not a sugar-free urine or a low blood sugar but the maintenance of the patient in health and vigour. This can be accomplished in severe diabetes only by insulin. The object of regulation of meals should be not the maintenance of a carbohydrate balance but the avoidance of hypoglycaemic attacks. Glycosuria implies a regrettable waste of good foodstuffs, but an abundant glycosuria is not incompatible with sustained health and vigour.

Overriding all rules should be the maxim that the right line of treatment for each individual diabetic is that line of treatment on which he is best able to maintain health and vigour over a prolonged period. A lifetime of study may be necessary to make sure that years of apparent good health do not conceal the insidious development of arteriosclerotic or degenerative processes. For that reason I make a plea for the prolonged study of the group of persistently hyperglycaemic (but otherwise healthy) diabetics, for in this study lies the final justification or refutation of the need for strict dietetic control.

Insulin

Insulin in solution is usually given in preference to insulin suspension, the chief reason for the preference being that it demands less complicated instructions as to the prevention of hypoglycaemic attacks. In most cases of severe diabetes in adults two injections daily are found to suffice, but in many children a third (evening) injection is required to prevent a morning ketosis. The total daily dose varies with different cases between 10 and 60 units. If the dose is too low polyuria will probably attract the patient's attention, the urine at some periods of the day will contain ketones, and the weight will fall. If the dose is too high hypoglycaemic attacks will occur in spite of the fact that the patient is eating freely and frequently.

Patients are taught to weigh themselves often and to report at once any substantial change of weight. They are also taught