REVERSED-EAR SYNDROME AND THE MECHANISM OF BAROTRAUMA

BY

ANTONY JARRETT, M.Sc., M.B.

Surgeon Lieutenant, R.N.

"Reversed ear" is a term which has long been current among professional divers, but the first medical description was published this year after observations on naval frogmen (Jarrett, 1961). Divers have assumed that the injury is *outward* bulging and rupture of the drum (Cousteau, 1953), but in fact the drum is never involved, and the condition is one of barotrauma to the external auditory canal.

The external pressure encountered in diving tends to push the drum inwards, a tendency which must be counteracted by blowing air through the eustachian tubes by the Valsalva manoeuvre. Failure to clear the ears in this way causes *inward* rupture of the drum, not an uncommon injury among divers but clinically quite distinct from reversed ear, which is caused by totally different factors. The distinction between ruptured ear-drum and reversed ear is important, as the prognoses are so different; as amateur skin-diving is so rapidly becoming popular both conditions are likely to be seen more often in civilian practice.

The mechanism of reversed ear is particularly interesting as it throws light on the mechanism of barotrauma in general, whether caused by diving or flying, whether affecting the ears, the sinuses, or the lungs.

Clinical Observations

Fourteen cases of reversed ear were seen in a group of naval frogmen during the last four months of 1960, an overall incidence of roughly 0.5% of all dives made by the group during this period. There are no symptoms of reversed ear. In some cases the diver remembered some temporary difficulty in clearing his ears during descent; this is so common in all divers that it cannot be specifically related to reversed ear, and 9 of the 14 cases had no pain or difficulty of any kind. The gross sign of reversed ear is blood on the pinna, but lesser

signs may coexist with this or be found in its absence. Twenty-volume hydrogen peroxide is useful for clearing blood and debris from the ear and making a detailed examination possible, and was incidentally found to reduce the average recovery time from 14 days (4 cases, mean deviation 3 days) to 6 days (9 cases, mean deviation 1.6 days). When the ear has been cleared one or more of three abnormalities may be seen. There may be subcutaneous petechiae in the meatus, or these may have progressed to blood-filled subcutaneous blisters which may be large enough to fill most of the lumen (Fig. 1).

If blood has appeared on the outer ear one such blister is oozing or has burst, and in this case ragged curtains of skin are seen surrounding a bleeding area devoid of skin. In those cases with petechiae only or in which the blisters had burst there was an unobstructed view of the drumhead, and in no case was any abnormality seen—it was always intact and freely mobile both by the Valsalva manoeuvre and by Siegle insufflation. In only one case was the drum indirectly involved; a haemorrhagic blister arising from the postero-inferior part of the bony canal had extended medially, lifting the skin from the periosteum and eventually extending between the cutaneous and fibrous layers of the drum in its postero-inferior sixth. The rest of the drum was normal, and indeed the whole tympanic membrane moved normally with the Valsalva manoeuvre, though the diver felt that his ear was not clearing properly. In three other cases divers said that their affected ears would not clear, but irrigating the meatus with hydrogen peroxide abolished this sensation, which was presumably due to debris resting on the drumhead.

Treatment

In cases of reversed ear, diving must be forbidden till healing is complete or petechiae may progress to bullae. It is most important to prevent infection of the damaged meatus. Hydrogen peroxide was the only local agent used, and those affected were told to keep the water out of their ears when washing and to avoid the apparently archetypal impulse to stuff them with cotton-wool. All the cases in this series were also given prophylactic sulphadimidine, 1 g. t.d.s.; but the necessity for this is speculative, as there were no controls. Infection did not occur in any of the cases, and all but one were completely healed within two weeks of injury. The only case to persist beyond this period was that in which blood had extended between the layers of the drum, where it formed a clot which remained for over six weeks.

Aetiology

The body fluids are incompressible, and any increase in pressure is transmitted equally without any tendency to compress or distort. Air, on the other hand, is compressible, and to prevent the distortion or collapse of the respiratory tract and its appendages the air within them must be kept at the external pressure. When the pressure everywhere in the body is the same—in air spaces and in tissue fluid—body sensation and function are quite unaffected.

Modern divers achieve this by breathing air which is automatically regulated to the external pressure no matter how this changes; this ensures that the air in the lungs, paranasal sinuses, and middle-ear spaces will always be at the external pressure (Fig. 2), provided the

FIG. 1.—Haemorrhagic bulla arising from supero-posterior part of right external meatus.

ears are cleared and the ostia of the sinuses patent. Their equipment is completed by a flexible rubber suit and hood, which should transmit the external pressure to every other part of the body (Fig. 3). Unfortunately, watertight rubber suits do not seem to do their job properly, for during and after a dive there is a most noticeable partial vacuum within the suit—invariably the first act on leaving the water is to pull the hood away from the face to let in a rush of air. This lowered pressure in the suit and meatus would certainly cause the drum to bulge outwards, but this in itself is harmless; it occurs in the Valsalva manoeuvre, which never causes pain or damage to a healthy drum (Mr. John F. Simpson, personal communication) even though intratracheal pressures of 450 mm. Hg may be produced (Faulkner and Sharpey-Schafer, 1959). However, this does not dispose of the lowered meatal pressure as a possible cause of reversed ear.

An increased external pressure has an effect which is often overlooked. As the body is immersed in water the blood-pressure is increased by the pressure of the water by direct fluid transmission. Of course, the systolic/diastolic difference remains the same, and as the tissue fluid pressure is also increased by the external pressure the peripheral resistance and work of the heart remain almost unchanged—they are in fact slightly lowered owing to the reduced head of hydrostatic pressure within the vascular system. But, as we have seen, the pressure within a watertight rubber suit, and therefore in the external meatus, is less than the external

pressure, and the increased blood-pressure will tend to passively dilate the blood-vessels on the surface of the body. Actual dilatation cannot occur where the surface of the body is supported by the external pressure through the direct contact of the suit, but, of course, there is no such contact or support for the skin of the external meatus. The skin in this situation is closely attached to the periosteum, and there is very little elastic subcutaneous tissue in which the vessels of the rete arteriosum cutaneum can expand. Any tendency to do so will split the skin from the periosteum, forming first petechiae then bullae—precisely the damage seen in reversed ear.

It was decided to test this hypothesis by measuring the extent of the partial vacuum in a suit during a dive, and seeing whether this order of negative pressure would produce the damage seen in reversed ear when applied to the meatus under experimental conditions.

Experimental Observations

The usual diving-dress comprises a suit and a hood which are clamped together so that the space within is continuous over the whole head and body, but excluding the hands and face (Fig. 3). For the following experiments a special neck seal was worn instead of the hood to exclude the ears from the partial vacuum formed in the suit and avoid damage to them. The suit was connected to a pressure gauge with the zero adjusted to allow both positive and negative pressures to be read; it was recalibrated in a pressure-chamber. The exterior of the Bourdon tube was exposed so that the gauge would register the difference between the external pressure and that within the suit.

Four dives to 80 ft. (24.4 m.) were made, measuring depth at the subject's suprasternal notch, and the gauge reading was recorded at intervals of 10 ft. (3 m.). For convenience these dives were made in an open diving-bell in which the subject was submerged to the suprasternal notch; this made diving-masks unnecessary and allowed the gauge to function normally in the pocket of air under the bell (Fig. 4).

The findings are shown graphically in Fig. 5, from which it can be seen that as the depth of the dive increases so does the partial vacuum within the suit, reaching a maximum under these conditions of -12.75 lb./sq. in. (-0.896 kg./sq. cm. or -659 mm. Hg). The graph does not pass through the origin, for as the diver submerges some air is squeezed from his suit through the cuffs and neck seal. This permanent diminution in

FIG. 2.—Valve V always supplies air at pressure of water surrounding it—all parts marked with an asterisk are at same pressure. The stippled area represents tissue fluid at pressure of surrounding water. (C=cylinder.)

FIG. 3.—Watertight rubber suit showing face and cuff seals.

the volume of the suit is resisted by the elasticity of its material and gives rise to the residual partial vacuum of some -10 mm. Hg, which is determined solely by the degree of venting and not by the depth of the dive. *It is, of course, this same elastic resistance to compression which causes the partial vacuum within the suit throughout the dive.*

FIG. 4.—Determination of pressures within a watertight suit, using an open diving-bell.

FIG. 5.—Relationship between depth of a dive and the partial vacuum existing within the suit. Observations in four determinations were identical, variation being less than the discrimination of the gauge. (0.25 lb./sq. in.)

Having determined the negative pressure occurring in a diving-suit it remained to apply negative pressures of this order to the external meatus while observing it continuously for signs of damage. This was achieved by attaching a pressure-sealed Siegle's speculum to the upper end of a mercury manometer. The speculum was applied to the subject's meatus and sealed in with petroleum jelly, while the meatus and the drum were observed by myself with the aid of a head-light (Fig. 6), while the whole set-up—subject, speculum, manometer, and observer—was contained in a large compression chamber. When the pressure in this was gradually increased it acted on everything within it except the subject's external meatus, which had been sealed off in the way described. The extent of the partial vacuum within the meatus was directly recorded by the manometer.

FIG. 6.—Arrangement used to observe the meatus while at a pressure below ambient. Both subject and observer were in a compression chamber throughout.

In the first experiment the pressure in the chamber was increased till the manometer stood at 120 mm. Hg. At this point the drum was only slightly injected along the handle of the malleus though bulging outwards most markedly, and the experiment was terminated as bright red petechiae had appeared in the swollen meatal walls. In a second experiment petechiae appeared in the meatal walls at 150 mm. Hg negative pressure, but before pressure could be restored to normal several postero-superior petechiae had coalesced to form a haemorrhagic bulla about 7 mm. in diameter. In both cases the tympanic membrane appeared quite normal on returning to atmospheric pressure. Only the petechiae and bulla persisted, the oedema of the meatal walls disappearing as the negative pressure was released. No skin was broken, and both ears were completely normal in four days.

The pressure causing this damage corresponds to the partial vacuum within a suit when diving 30 to 50 ft. (9 to 15 m.) below the surface, which is in fact the depth range at which the great majority of cases of reversed ear do occur.

Discussion

The basic cause of the reversed-ear syndrome is that the watertight rubber suit converts the external meatus into a closed cavity within which the pressure may fall below that of the body tissues. When this happens the blood-vessels in the skin of the meatus are passively dilated by the excess blood-pressure, with resultant dilatation and rupture. This situation can be generalized; if in any body cavity the pressure falls below that of the body tissue (which is always equal to the

external pressure by direct fluid transmission) the vessels lining the cavity will respond in the same way.

The best-known situation in which this occurs is the middle-ear cavity when descending in an aircraft. While at altitude the pressure in the middle ear falls, as air can always escape passively from the eustachian tube. As the aircraft descends the barometric pressure rises, and unfortunately air will not passively re-enter the eustachian tube but must be made to do so by a conscious effort. If this effort is not made or is inefficiently carried out, or if the eustachian tube is blocked by an infection of the upper respiratory tract, the pressure in the middle ear falls below that in the rest of the body. The vessels in the middle ear are then passively dilated, with consequent reddening of the drum and transudate into the middle-ear cavity, so-called aero-otitis media (Armstrong, 1939). The indrawing of the drum which occurs is a mechanical concomitant of these effects and not their cause. Its main danger is that rupture occurs when the mechanical tolerance of the drum is exceeded, but pain and deafness occur before this limit has been reached and, most significantly, remain long after the drum has returned to its normal position.

The same mechanism explains the haemoptysis which sometimes occurs in those who dive without breathing apparatus. When diving with the breath held the thoracic cage must collapse to equalize the pressure in the lungs; this process is limited when the lungs approach residual volume. If the diver descends below this point the pulmonary vessels dilate and may rupture. This injury occurs in native pearl-divers and skin-divers using schnorkel masks. Infection of the upper respiratory tract may close the ostia of the paranasal sinuses, converting them into closed spaces in which a falling pressure can cause similar bleeding in addition to pain and congestion.

The danger of reversed ear is created by anything which closes off the external auditory canal, and ear-plugs are worse in this respect than a frogman's suit. They should never be worn when diving or when travelling by air; when descending in either situation they may not only cause reversed-ear injury but may be driven inwards by the increasing pressure and cause direct trauma of the drum. If an amateur skin-diver wishes to wear a suit in cold waters he should choose one made of porous rubber. This will never cause reversed ear, as a porous material cannot possibly maintain a partial vacuum, and the petechiae which form in the skin under the wrinkles of a watertight suit are, of course, never seen. A porous type of suit maintains body temperature quite efficiently, as it fills with and holds water in the same way as a woollen garment normally fills with and holds air.

Barotrauma may occur in other artificial cavities; some goggles worn by amateur skin-divers form a closed cavity in front of the eyes, and diving in these has caused serious conjunctival haemorrhage. Goggles worn for this purpose should cover the nose as well as the eyes so that air can be blown into them to equalize pressures during descent.

Summary

The clinical features, treatment, and prevention of the reversed-ear syndrome are discussed. It is a condition of barotrauma to the external auditory canal and is characterized by petechiae, bullae, and rupture of the skin in the meatus. It occurs when the pressure in the

external canal falls 100–200 mm. Hg below that in the body tissues, in which circumstance the blood-vessels in the skin will be passively dilated to give rise to these signs. The syndrome has been produced and observed experimentally since its original observation among professional divers. Similar injury will occur in any body cavity which falls below external pressure, and the significance of this in aviation and diving is discussed.

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PLASMA CHOLESTEROL LEVELS IN NEW ZEALAND

OBSERVATIONS IN 1,000 URBAN MALES

BY

J. D. HUNTER, M.B., M.R.C.P., M.R.A.C.P.
Senior Lecturer in Medicine

AND

L. C. K. WONG, M.Sc.
Research Assistant

*Department of Medicine, University of Otago, Dunedin,
New Zealand*

In New Zealand the high incidence of deaths due to coronary artery disease is similar to that found in other highly westernized countries such as the United States of America, Australia, Canada, and the United Kingdom (World Health Organization 1955, 1956). Numerous well-planned surveys throughout the world have shown the close association between the prevalence of coronary artery disease in a population on the one hand and the mean blood cholesterol concentrations on the other (Keys *et al.*, 1952, 1958; Bronte-Stewart *et al.*, 1955). Relatively high cholesterol levels have been found in inhabitants of some of the aforementioned countries—for example, the United States and the United Kingdom—and also in Finland. In populations so characterized, one of the most constant features has been the trend for cholesterol levels to increase with age (Keys *et al.*, 1950, 1958; Keys, 1956; Lawry *et al.*, 1957; Lewis *et al.*, 1957).

From New Zealand—a country reputed to have a *per capita* consumption of total fat as high as or higher than in any other nation (Food and Agriculture Organization, 1955)—there have been no previous surveys relating to blood cholesterol values in the population.

The study to be described was undertaken in 1,000 apparently healthy adult males from an urban community. The purpose was to determine the mean fasting plasma cholesterol levels and to analyse such findings in relation to occupation, body weight, and smoking habits at various ages. While, as might be expected, the major findings are similar to those noted in other westernized communities, there are certain features which differ and give food for further thought.