A NEW THEORY ON THE DYNAMICS OF BRAIN CONCUSSION AND BRAIN INJURY*

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IN THE design and evaluation of protective headgear, there is need for the establishment of physical criteria upon which the performance of helmets subjected to impact can be determined. In the present state of the protective helmet art, there is little agreement regarding either the significant parameters to be measured or their critical threshold values. It is agreed, however, that the primary function of the helmet is to provide protection from brain concussion in case of accidental impact to the head. An extensive search of the literature has revealed theories relating to the mechanism of brain concussion and brain injury by Gama,6 Duret,5 Miles,10 Russell,12 Munro,11 Goglio,7 Denny-Brown and Russell,4 Courville,2 Gurdjian and Webster,8 Holbourn,9 Walker, Kollros and Case,13 Ward, Montgomery and Clark14 and others. None of these theories, however, was found to be sufficiently comprehensive to enable the establishment of the desired criteria. An excellent review of the development of the current knowledge of brain concussion has been presented by Denny-Brown.3

If it can be established that brain concussion is produced by, or occurs simultaneously with, a specific detectable physical phenomenon occurring within the head, it then may be possible to obtain considerable information on the threshold of concussion from research on impact on human cadavers. The data from such research could then be used to establish a standardized set of laboratory test conditions for the evaluation of helmets subjected to impact.

The subject of brain concussion is normally the exclusive concern of those in the medical profession. Research in the field of brain concussion has, in the past, accordingly been conducted mainly by those trained in the field of medicine. It must be recognized, however, that research dealing with impact to the head involves engineering dynamics, a highly specialized field that is normally foreign to the medical researcher. Lack of a clear understanding of the dynamics involved in impact to the head has served as a considerable handicap to these researchers.

The basic purpose of this research effort has been to investigate the dynamics of the head and its contents when subject to impact. The actual experimentation involved was limited to the study of the dynamics of fluid-filled glass flasks simulating the human head. Although the medical literature

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on brain concussion was carefully reviewed for guidance of this study, the actual research was of an engineering nature, conducted by engineering personnel.

**BASIC DYNAMIC CONSIDERATIONS**

Since this is a problem in dynamics let us start with Newton's first law of motion: Force equals mass times acceleration.

If we take the simple case of a bar being accelerated from one end by a tension force, as shown in Fig. 1, we shall find that the distribution of tensile force in the bar will be maximum at the end the tensile force is being applied, graduating to zero at the other end. The tension at any point along the bar will be proportional to the remaining mass being accelerated.

![Fig. 1 (left). Tensile stress gradient in a bar being accelerated by a force at one end.](image1)

![Fig. 2 (right). Tensile stress gradient developed in the fluid, contained in a simple test tube, because of the downward acceleration of the tube produced by impact to the top of the tube.](image2)

Let us now take a similar case in which tension is developed in a fluid, as shown in Fig. 2. If a glass tube partially filled with a fluid is struck on the top, the fluid will be accelerated downward by the tensile force developed in the fluid itself. The distribution of the tensile force in the column of fluid will be proportional to the mass of fluid above the level considered, being maximum at the bottom and zero at the surface of the fluid. If the tube is given a sufficiently hard blow so that the tensile force exceeds the tensile strength of the fluid, the fluid will tear apart, producing temporary cavities. Since the maximum tensile force is developed at the base of the fluid column, failure of tension or cavitation can be expected at this point. This phenomenon is demonstrated in Fig. 3.

Let us now take the case in which the glass tube is sealed at both ends and completely filled with a fluid as shown in Fig. 4. Neglecting radial expansion of the tube and assuming the compressibility of the fluid to be greater than the compressibility of glass, we can conclude that the fluid...