THE MECHANICS OF TRAUMA WITH SPECIAL
REFERENCE TO HERNIATION OF
CEREBRAL TISSUE

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The general theory of trauma will be developed in this paper by means
of the theory of elasticity. Once the theories of trauma and intracranial
mechanics have been put on a firm basis, it is possible to discuss
particular examples of traumatic intracranial tissue damage, and to compare
the theoretical predictions with the observed facts, thereby testing the gen-
eral theory. The experimental investigation of herniation of cerebral tissue
through a defect in the skull, reported in the preceding paper by Falconer
and Russell, is an excellent subject on which to test the general theory. Be-
cause of the definite nature of the experiments, and the results obtained,
the test of general theory is stringent. It will be shown that there is good
agreement between theory and experiment.

THE FUNDAMENTAL CONCEPTS OF THE THEORY OF ELASTICITY

The theory of trauma is really a branch of the theory of elasticity. Hence,
before the theory can be developed, it is necessary to have a general under-
standing of the theory of elasticity. A simple explanation of the underlying
principles is given to help readers who may be unfamiliar with the subject.

The technical meaning of the word stress is a force per unit area. It is
quite different from strain, which is roughly speaking a displacement of one
part of a body relative to another part. A strain may often be regarded as
the consequence of a stress.

A hydrostatic pressure is an example of a simple type of stress. It is
uniform in all directions. The pressure of cerebrospinal fluid in the ventricles
is a true hydrostatic pressure. But elsewhere in the brain, at any rate in
many pathological conditions, the stress system is vastly more complicated,
so that it cannot be described by one single quantity such as hydrostatic
pressure. A complete specification of the state of stress at any point within
the brain substance requires six components at each point. Only when three
of these components are all equal, and the remaining three are all zero is
there a hydrostatic pressure at the point considered. This will not in general
be true. Hence the expression “intracranial pressure” is in general meaning-
less and will be avoided in what follows. It is well known (Cairns, 1939) that
one single quantity, such as “intracranial pressure,” having the same value
throughout the brain does not adequately describe conditions in the brain
where expanding tumours are present. It often appears somewhat as
if the hydrostatic pressure were higher near the tumour than elsewhere. It
is not sufficiently realised, however, that different hydrostatic pressures could not coexist at two points in the brain unless there also existed non-hydrostatic stresses at other points.

It is convenient to divide the six components of stress into two sets of three which are of different types. Three consist of forces acting perpendicular to surfaces and are called pressures or tensions, and three consist of forces acting tangential to surfaces and are called shearing stresses. From the point of view of their destructive effect on substances, the shearing stresses are much more important than the others.

These shearing stresses are responsible for a sliding motion of one layer of a substance upon another. As a representation of what happens one may consider a neat and squarely piled pack of playing cards. If, by applying the palm of the hand to the top card and pushing in the direction of the surface of the card, one could slide each card a little relative to the one below, so that the pack changed from the shape shown on the left hand side of Fig. 1 to that shown on the right, then it would be a representation of a shearing stress causing a shearing or sliding strain. Note that the shape on the side of the pack has changed from a circle to an ellipse. This is an example of a strain ellipse.

It is often helpful to have a mental picture of the stresses at a point in a body. A hydrostatic pressure, which is a stress uniform in all directions, may be visualised as a sphere, which is obviously a shape that is uniform in all directions. The diameter of the sphere represents the magnitude of the pressure. The most general stress system at a point may often be visualised as a shape like a plum stone or ellipsoid, having an existence at the point considered. The pressure is greatest in the direction of the longest axis of the ellipsoid, and least in the direction of the shortest axis, and so on. A body subjected to the most general type of stress may be thought of as filled with little ellipsoids whose sizes, proportions and orientations vary from point to point in the body.

If the pressure is a purely hydrostatic one, represented by a sphere, there are no shearing stresses. But if the pressure is not a hydrostatic one—i.e., if its representative sphere has been distorted into an ellipsoid—shearing stresses are present. The greater the difference between the largest and

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**Fig. 1.** Pure shear strain in a pack of cards. Note that the circle is deformed into an ellipse—an example of a shear ellipse.