A MODEL OF THE EXTRADURAL SPACE AND A REAPPRAISAL OF THE EXTRADURAL SPACE PRESSURE

G. R. HARRISON

Although the existence of a pressure in the extradural space has been acknowledged for 60 years, the cause of this phenomenon is disputed. The following proposals have been advanced to explain the genesis of the extradural space pressure:

(1) The negative pressure in the extradural space is an artefact, which is caused by dural dimpling (Janzen, 1926; Bonniot, 1934; Eaton, 1939).

(2) The negative pressure in the extradural space is an artefact, which is caused by the retraction of the ligamentum flavum around the epidural needle (Zarzur, 1984).

(3) The negative pressure is the result of transmission of the negative intrathoracic pressure through the intervertebral foramina into the extradural space (Zorraquin, 1936; Macintosh and Mushin, 1947; Macintosh, 1950).

(4) The negative pressure is attributable to the disproportionate growth of the vertebral canal compared with the dural sac (Heldt and Maloney, 1928).

(5) The negative pressure is a temporary phenomenon caused by stretching the dura mater when the back is flexed (Odom, 1936).

(6) The pressure changes in the extradural space are related to changes in the cerebrospinal fluid pressure, causing the dural sac to bulge, thereby producing a positive pressure, or to collapse, producing a negative pressure (Bryce-Smith, 1950).

(7) The positive pressure is produced by the transmission of the pressure in the subarachnoid space through the dura mater to the extradural space (Shah, 1981).

The existence of so many theories for the genesis of the extradural space pressure raises two important questions. First, what do clinicians mean when they describe the pressure in the extradural space and, second, which of these theories, if any, explains adequately the genesis of such a pressure? A model of the lumbar spinal canal, which could be used in vitro to reproduce some of the changes which have been recorded in vivo, has been designed and studied, in an attempt to arrive at an answer to these questions.

MATERIALS AND METHODS

The model comprised two parts. The outer shell, corresponding to the vertebral canal, was a Perspex cylinder, at various points along which holes had been drilled and covered with rubber septa to allow the insertion of needles. The inner layer, corresponding to the dural sac, was Paul's tubing. The top end of the Paul's tubing was everted over the end of the Perspex outer tube, and a bung inserted, through which ran a tube connected to a constant pressure device providing a pressure of 18 cm H₂O. The bottom end was tied off, and a bung inserted to the bottom of the Perspex tube (fig. 1). The inner tube was filled
with water, representing the cerebrospinal fluid (CSF); the layer between the inner and outer tubes represented the extradural space.

The changes in pressure on inserting an epidural needle were measured. A Tuohy needle was attached directly to the dome of a transducer, both being filled with water. The needle was inserted through the rubber septum, and the pressure changes measured, both at the needle, and at other points in the "extradural space". The pressures were recorded using a Bell and Howell transducer and an Elcomat multichannel u.v. recorder.

Subsequent tests were designed to reproduce the findings of other authors. Two methods used to define the extradural space—the hanging drop technique of Gutierrez and the Macintosh balloon—were tested. For the hanging drop test, the Tuohy needle was inserted to the septum so that the tip was covered, and enough water was inserted to the hub of the needle to create a hanging drop. The needle was then pushed into the "extradural space", and the effect on the hanging drop was observed. The pressure inside the Paul's tubing was then altered by varying the height of the constant head of pressure apparatus, and the effect on the hanging drop noted.

With the Macintosh balloon, the balloon was connected to the Tuohy needle by a four-way tap, the third arm of which was connected to a transducer of the type described above by a short length of narrow-bore tubing. Both the tubing and the dome of the transducer were filled with water. With the tip of the needle in the septum, 2 ml of air was injected to the balloon, and the pressure within the balloon measured. The needle was then advanced until it entered the "extradural space". The new pressure was recorded. The effect of altering the pressure within the Paul’s tubing, as described above, was noted.

Finally, a Portex epidural catheter was inserted to the "extradural space" and 0.5 ml of water was injected to the catheter, which was then held vertically as described by Shah (1981). The height of water in the catheter above the point of insertion was measured. This initial manoeuvre was repeated until a constant level could be recorded. This procedure was performed with the model in both the horizontal and upright positions.

**RESULTS**

When the Tuohy needle was inserted, there was a decrease in pressure to $-30$ cm H$_2$O, with the needle inserted 5 mm to the "extradural space". The pressure returned to zero when the needle was withdrawn. Indentation of the Paul’s tubing was noted. All pressure changes recorded were found to be independent of the position of the model. Whilst these changes were recorded, there were no changes noted in the pressure in the "extradural space" at other points along the tube.

The two methods used to define the extradural space responded as they have been observed to do in the clinical situation. With the hanging drop technique, insertion of the needle to the "extradural space" caused the hanging drop to disappear into the hub of the needle. The drop could then be made to oscillate backwards and forwards by cyclically varying the pressure of the water inside the Paul’s tubing. The Macintosh balloon responded in a manner similar to that seen in clinical practice. When the tip of the needle was in the septum, the balloon remained expanded, but it collapsed immediately the tip of the needle entered the "extradural space". The balloon could be
made to re-expand partly when the pressure in the Paul's tubing was increased. The initial pressure recorded in the balloon was 47 cm H$_2$O. When the pressure inside the "extradural space" was measured after the Macintosh balloon had deflated, it was found to be 16 cm H$_2$O.

In the final test when the epidural catheter was used as a water manometer, the water level initially decreased rapidly, producing a pressure of only 2 cm H$_2$O. However, when the test was repeated the pressure was found to increase on each occasion until a limiting pressure was produced. The limiting pressure produced was dependent on the position of the model, but in all measurements made the value was 1 cm H$_2$O less than the hydrostatic pressure at the position of the catheter tip.

**DISCUSSION**

The four different clinical techniques assessed in the model behaved as they do in vivo. Insertion of the Tuohy needle produced a negative pressure, which was associated with indentation of the Paul's tubing. The greater the indentation, the greater the change in pressure, a fact which accords with the findings of Janzen (1926) and Eaton (1939), and suggests that the negative pressure is caused by the distortion of the dura mater. This also confirms the findings of Aitkenhead and colleagues (1979), who demonstrated that dural dimpling occurred in dogs, and showed that the negative pressure was a function of the amount of dural displacement. Evidence of dural dimpling in man was provided by Orrison, Eldevik and Sackett (1983), who demonstrated this phenomenon whilst performing cervical myelograms.

The Macintosh balloon could be made to re-inflate partially by increasing the pressure in the Paul's tubing and, similarly, the hanging drop could be made to oscillate with fluctuations of the pressure of the Paul's tubing. These findings agree with those of Macintosh (1950), but they do not confirm his belief that the pressure in the extradural space is dependent upon the pressure in the thoracic cavity. It is more probable that the changes he noted with ventilation were related to changes in the CSF pressure secondary to ventilation.

Initially, repeating the work of Shah (1981) gave rise to results which differed from his. The production of such a low pressure may be related to the presence of a space between the rubber septum and the Paul's tubing, which has to be filled with fluid before any measurement can be made, and this will accommodate 0.5 ml of water. However, continuing to fill the "extradural space" with water will produce a situation similar to the extradural space compliance tests of Bengis and Guyton (1977), which will produce an extradural space pressure tending towards the pressure within the lumbar CSF, but not reaching it, as a result of part of the pressure being responsible for keeping the dural sac distended. Thus, regardless of the position of the model, the height of the water in the extradural cannula will approximate to, but can never equal, the pressure within the Paul's tubing. A similar situation was produced with the experiment using the Macintosh balloon.

Although it has been shown that these clinical phenomena can be reproduced in vitro, the limitations of the model must be taken into account. This model was designed to be simple, and therefore cannot be as detailed in its construction as the lumbar spine. The Paul's tubing was not attached to the inside of the Perspex outer tube at any point other than at one end—a difference from the situation in vivo (Parkin and Harrison, 1985). The closed end of the Paul's tubing was free within the outer tube—although this situation was not totally dissimilar to that in the body, where the end of the dural sac is free to move up or down to a limited extent (Martins, Wiley and Myers, 1972). One notable absence in this model was the internal vertebral venous plexus. This may play a role in determining the pressure in the extradural space, but it was considered difficult to design a component of this model which would correspond to this venous plexus.

It is suggested that the pressure being measured in the extradural space in vivo is not the pressure native to the extradural space, but an artefact created by the introduction of a needle or catheter—a conclusion reached by Janzen in 1926. Furthermore, it is suggested that the pressure measured in the extradural space is an artefact of the method used to measure it. Thus if a needle which causes the dura to be displaced away from the walls of the vertebral canal is inserted, the pressure recorded will be negative on the condition that no air is allowed to enter. On the other hand, if a catheter is inserted to the extradural space, and fluid is allowed to enter, the pressure recorded will be related to the
pressure between the dural sac and the vertebral canal. These findings support both Janzen’s (1926) and Shah’s (1981) theories for the genesis of the pressure in the extradural space.

It is the author’s opinion that the pressure in the extradural space is not a single measurable entity, but a complex dynamic equilibrium of forces which exist between the vertebral canal, the contents of the extradural region, and the dural sac. Because of this it might be better if performers of extradural injections were to content themselves with the fact that various clinical phenomena exist, which they can use to their advantage, rather than to attempt to create a holy grail out of the pressure in the extradural space.

REFERENCES