

EFFECT OF EXTRADURAL COMPLIANCE AND RESISTANCE ON SPREAD OF EXTRADURAL ANALGESIA

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SUMMARY

We have studied the effect of extradural compliance and extradural resistance on the spread of extradural analgesia. In 111 patients aged 21–75 yr, compliance and resistance of the extradural space were calculated by a mathematical analysis (using the Windkessel theory) of the extradural pressure–response curve to injection of a given volume of local anaesthetic. The calculated mean extradural compliance was 0.39 (SD 0.13) ml mm Hg⁻¹ and this increased with advancing age ($P < 0.01$). The total number of analgesic segments blocked was related to extradural compliance ($P < 0.01$). Segmental dose requirement was related inversely to extradural compliance ($P < 0.01$). Calculated extradural resistance was 26.8 (14.5) mm Hg s ml⁻¹ and this decreased with advancing age ($P < 0.05$). The total number of analgesic segments blocked was related inversely to extradural resistance ($P < 0.05$). Segmental dose requirement was related to extradural resistance ($P < 0.05$).

KEY WORDS

Anaesthetic techniques: extradural.

The changes in extradural pressure caused by extradural injection of local anaesthetics have been thought to affect the spread of injected solution in the extradural space [1]. Despite the recognition that extradural compliance and resistance are related to the extent of analgesia, few controlled studies of these variables have been made [2, 3]. Our previous studies performed under standardized conditions in which local anaesthetics were injected into the extradural space at constant pressure [4] or speed [5], led us to believe that smaller changes in extradural pressure caused by extradural injections of local

anaesthetics results in increased spread of extradural analgesia.

We have studied the effect of extradural compliance or extradural resistance on the spread of extradural analgesia. Using the Windkessel theory [6] in a mathematical analysis of the extradural pressure–response curve to a given volume of local anaesthetic, we have measured the compliance and the resistance of the extradural space.

METHODS

Mathematical analysis

A pressure curve obtained during and following rapid extradural injection of local anaesthetic consists of two parts: the first part of the pressure curve occurs while the injection is delivered and the second one occurs after the injection has terminated (fig. 1). The first part (expansion of the extradural space induced by a given volume of fluid) is often termed the “forced response curve”, whereas the second part is often termed the “free response curve” [6]. The speed of injection plays a major role in determining the forced response curve. Extradural compliance and resistance play important roles in determining both the forced response curve and the free.

We considered that the extradural pressure (P) may obey the following relationship through the Windkessel theory:

$$C \cdot \frac{dP}{dt} + \frac{1}{R} \cdot P = i$$

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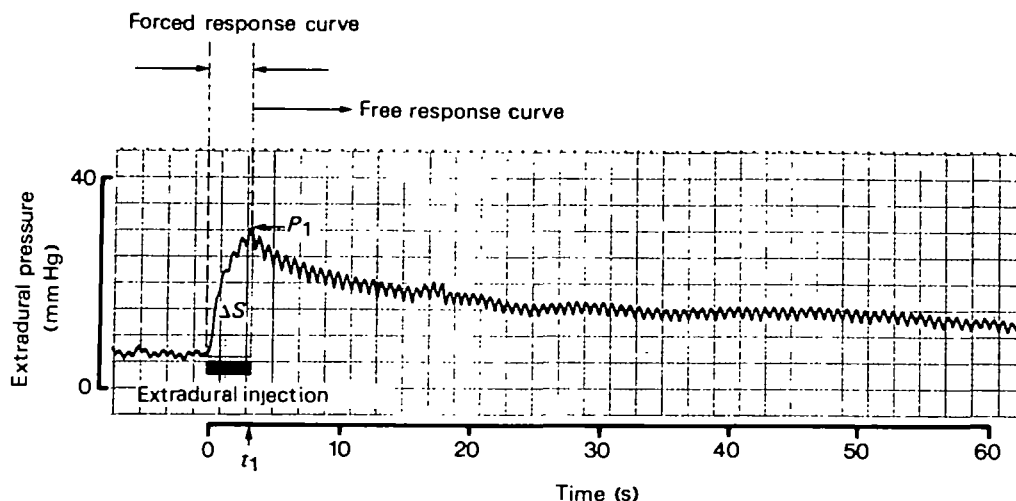


FIG. 1. Typical extradural pressure-response curve obtained during and following the extradural injection of 2% mepivacaine 10 ml.

where C = extradural compliance, dP/dt = first derivative of extradural pressure with time, R = extradural resistance and i = speed of injection.

Integrating with respect to time, this becomes:

$$C \int_0^{t_1} \left(\frac{dP}{dt} \right) dt + \frac{1}{R} \int_0^{t_1} P dt = \int_0^{t_1} i dt \quad (1)$$

where t_1 = injection time, $\int_0^{t_1} (dP/dt) dt$ = peak extradural pressure measured at termination of injection (P_1), $\int_0^{t_1} P dt$ = area under the forced response curve (ΔS), and $\int_0^{t_1} i dt$ = total volume of injected solution (ΔV).

The free response curve occurs when the extradural space is not expanded and therefore it may be related primarily to the properties of the extradural space [7]. A straight line can be obtained by plotting pressure in the free response curve on a natural logarithmic axis against time. Therefore, extradural pressure of the free response curve obeys the following relationship:

$$P = P_1 \cdot e^{-t/T}$$

where T = time constant, and may be determined by the least square method from the pressure values in the free response curve. The following equation is obtained from equation (1) referring to $T = CR$:

$$C = \frac{\Delta V}{P_1 + \frac{1}{T} \cdot \Delta S} \quad (2)$$

Resolving equation (1) for R on referring to $T = CR$:

$$R = \frac{1}{\Delta V} \cdot (T \cdot P_1 + \Delta S) \quad (3)$$

Patients

We studied 111 patients aged 21–75 yr, requiring extradural analgesia for extracorporeal shock wave lithotripsy. Informed consent was obtained from each patient. Patients who had the following diseases were excluded: central nervous system disease, lumbar disc surgery, abnormalities of the vertebral column, abdominal distension caused by intestinal obstruction, ascites, tumour or pregnancy, and bleeding diathesis. Premedication comprised atropine 0.5 mg i.v. just before the extradural injection. The patient was placed in the right lateral position on a horizontal operating table. A 17-gauge Tuohy needle with the bevel pointing caudad was inserted into the extradural space at the T12–L1 interspace via a mid-line approach. The extradural space was identified by the “dripping infusion” method [8]. After the extradural space was identified, extradural pressure was measured continuously using a transducer (Yokokawa Hewlett Packard 78242A) calibrated (mm Hg) via a three-way tap. A second Tuohy needle with the bevel pointing cephalad was inserted subsequently into the extradural space at the L1–2 interspace via a mid-line approach. The extradural space was identified by

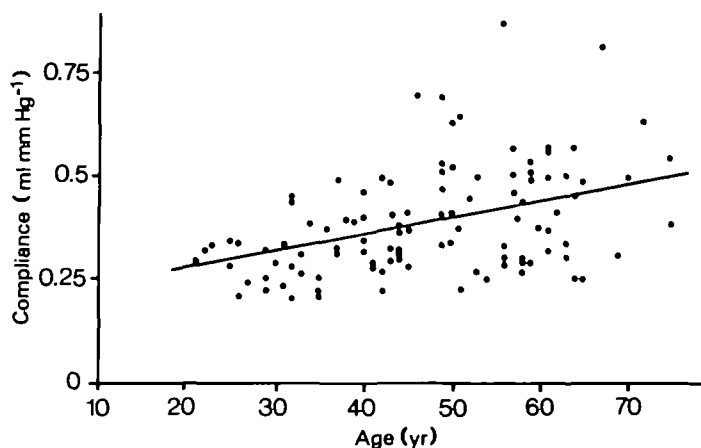


FIG. 2. Correlation between age and extradural compliance ($r = 0.40$; $y = 0.00406x + 0.20145$; $P < 0.01$).

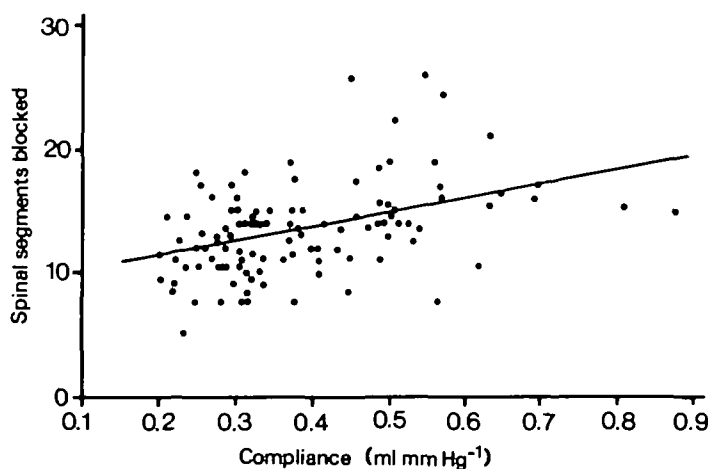


FIG. 3. Correlation between extradural compliance and extent of analgesia ($r = 0.40$; $y = 11.44x + 9.09$; $P < 0.01$).

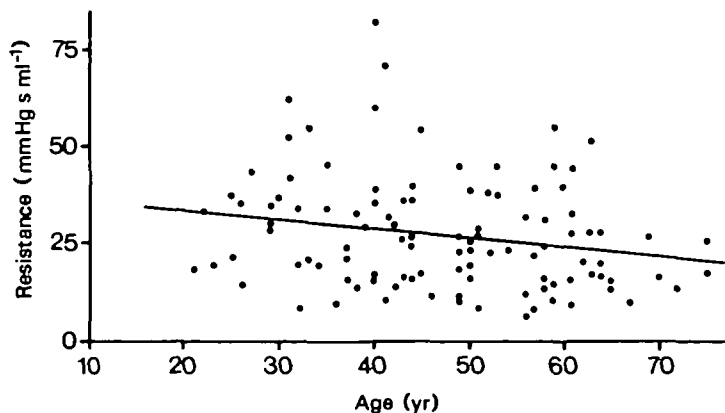


FIG. 4. Correlation between age and extradural resistance ($r = -0.22$; $y = -0.24x + 38.10$; $P < 0.05$).

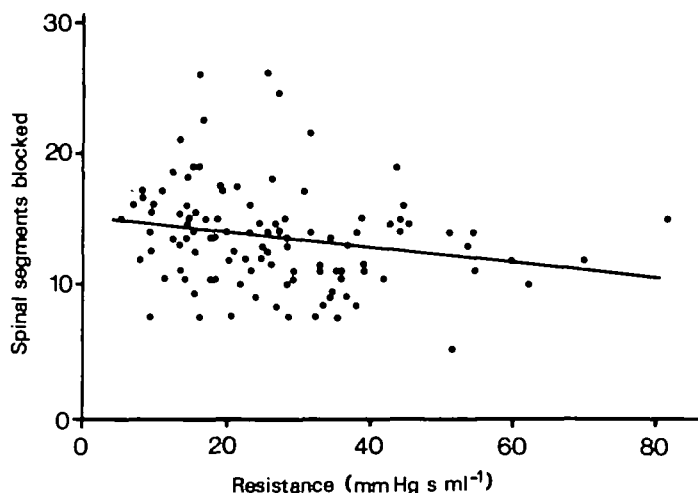


FIG. 5. Correlation between extradural resistance and extent of analgesia ($r = -0.22$; $y = -0.058x + 15.12$; $P < 0.05$).

the loss of resistance method. Before injection of local anaesthetic, the extradural pressure was allowed to equilibrate with atmospheric across the second Tuohy needle. When no cerebrospinal fluid or blood was aspirated through the second Tuohy needle, 10 ml of 2% mepivacaine (without adrenaline) was rapidly injected manually (mean injection time 2.3 (SD 0.7) s). The pressure curve obtained via the first Tuohy needle during each extradural injection and the pressure curve following completion of the injection were recorded continuously for 60 s on a recorder (Yokokawa Hewlett Packard 78172A) at a paper speed of 2.5 mm s⁻¹. An extradural catheter was then introduced and the patient turned to the supine position. Fifteen minutes after the extradural injection, the upper and lower extent of analgesia to pinprick was assessed [9]. The extent of analgesia was expressed by the average number of analgesic segments on each side. The volume of 2% mepivacaine required to block one spinal segment (segmental dose requirement) was calculated.

The relationships between extradural compliance or extradural resistance and the extent of analgesia were analysed by correlation coefficients. $P < 0.05$ was considered significant. Regression lines were calculated by the method of least squares.

RESULTS

The calculated mean extradural compliance was 0.39 (0.13) ml mm Hg⁻¹; this increased with advancing age ($r = 0.40$, $P < 0.01$) (fig. 2). The total number of analgesic segments was related to extradural compliance ($r = 0.40$, $P < 0.01$) (fig. 3). The segmental dose requirement was related inversely to extradural compliance ($r = -0.37$, $P < 0.01$).

The calculated extradural resistance was 27.1 (14.5) mm Hg s ml⁻¹; this decreased with advancing age ($r = -0.22$, $P < 0.05$) (fig. 4). The total number of analgesic segments was related inversely to extradural resistance ($r = -0.22$, $P < 0.05$) (fig. 5). The segmental dose requirement was related to extradural resistance ($r = 0.21$, $P < 0.05$).

DISCUSSION

This study has shown that the compliance and the resistance of the extradural space influenced the spread of solutions injected into the extradural space. We found that the greater the compliance and the smaller the resistance, the greater was the spread of extradural analgesia. Generally, more extensive analgesia was obtained by a small dose of anaesthetic solution in the elderly. This may be related to the fact that the extradural compliance increased and the extradural resistance decreased with advancing age.

The extradural space is a potential space [10] limited by the dura internally and by the connective tissue lining the space externally. It is regarded as a partially rigid but leaky container within which many elastic components are involved [1]. An analogy may be made with a compartmental system with compliant and resistant properties, especially when it is expanded with a given volume of fluid. When a semi-logarithmic plot of the free response curve has linear characteristics as shown in figure 1, this system has a first-order response with a time constant of T , and it may be characterized as one with compliance and resistance. Unfortunately, there is no direct way of measuring compliance and resistance of the extradural space. Application of the Windkessel theory to pulsatile injection of fluid into the extradural space is an indirect approach.

When a local anaesthetic is injected into the extradural space, initially it fills the space adjacent to the inserted needle, and creates pressure in the space. It may also create cephalad movement of CSF. Subsequently, injected solution travels along paths of least resistance. We postulated that the fatty tissue in the extradural space may play an important role in determining longitudinal spread of anaesthetic solution. The extradural space in young subjects is packed tightly with rigid fat [11] and has low compliance and high resistance; therefore, less longitudinal spread of injected solution occurs. As the fatty tissue degenerates with advancing age, the extradural space becomes more compliant and less resistant; therefore, greater longitudinal spread of injected solution occurs.

Our findings differ from the views of Bromage [1]. Based on the work of Usubiaga, Wikinski and Usubiaga [2], he considered that extradural compliance decreases with advancing age. Usubiaga's group measured the changes in extradural pressure following manual injection of lignocaine and showed that the higher residual positive pressure 2 min after completion of the injection resulted in increased spread of analgesia. They speculated that residual positive pressure is dependent on the patency of the intervertebral foramina. However, our previous studies (performed under standardized conditions in which 15 ml of mepivacaine was injected at constant pressure (80 mm Hg) [4] or at constant speed (1 ml s^{-1}) [5]) did not show any significant correlation between the residual pressure 1 min after

the injection and the extent of analgesia or the patient's age. Our findings were confirmed by a recent study which examined extradural pressure 1 min after injection of two different volumes of bupivacaine [3].

The reasons for the difference between Usubiaga's study and ours are not clear, but may be related to the fact that they measured residual pressure only 2 min after manual injection and the values for peak pressures were highly variable, whereas we examined changes in extradural pressure recorded continuously in response to a standardized automated injection. Anatomical studies in cadavers have suggested recently that the volume which spills out through the lateral intervertebral foramina is independent of their permeability, because lateral spread is confined to the area of cuffs surrounding spinal nerves [12] and because the displacement of CSF may act as a safety valve which limits the increase in extradural pressure [3].

In order to obtain accurate pressure-response curves, we injected local anaesthetics more rapidly than occurs in routine clinical practice. The forced response curve demonstrated a sharp increase at the rapid injection; the area under this curve (ΔS) was small and, therefore, the compliance and the resistance of the extradural space calculated by equations (3) and (4) should have a small error. Although rapid injection may cause patient discomfort and it is necessary to guard against the possibility of increased risk of local anaesthetic toxicity, this method permits measurement of both compliance and resistance of the extradural space, and it obviates inaccuracies observed in techniques using slow rates of injection.

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