Novel pulsatile cerebrospinal fluid model to assess pressure manometry and fluid sampling through spinal needles of different gauge: support for the use of a 22 G spinal needle with a tapered 27 G pencil-point tip

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Editor’s key points

- Post-dural puncture headache (PDPH) is a significant problem with larger bore spinal needles.
- This study investigated the flow characteristics of a tapered spinal needle (shaft 22 G and tip 27 G) using saline and mannitol.
- The flow characteristics were similar to a conventional 22 G spinal needle.
- This tapered needle may be associated with a lower incidence of PDPH.

Background. Parallel-walled spinal needles ≤22 G are routinely used for lumbar puncture, despite a reported ≥32% incidence of post-dural puncture headache. A tapered spinal needle (22 G shaft, 27 G tip) is in use in our institution. We hypothesized that despite the smaller dural puncture hole, this needle has similar cerebrospinal fluid (CSF) pressure equilibration times and CSF sampling times to a standard 22 G needle and assessed a range of spinal needles using an experimental pulsatile CSF reservoir.

Methods. The pulsatile CSF reservoir had an oscillating pressure varying between 25 and 15 cm H₂O at a cycle frequency of 80 s⁻¹. We tested seven parallel-walled spinal needles (18–27 G) and the tapered 22/27 G needle. CSF pressure was measured every 2 s by manometry. The time to collect 1 ml CSF samples was measured. Saline 0.9% and mannitol 20% were tested separately. One-way ANOVA with Bonferroni post-hoc test was used to compare 22G, 27G and 22/27G needles.

Results. The mean [standard deviation (so)] CSF pressure equilibration time (saline) was 40.7 (6.4), 108.7 (6.1), and 51.3 (4.6) s for the 22, 27, and 22/27 G needles (P < 0.0001 for comparisons between 27 G and other needles). The mean (so) CSF sampling time (saline) was 40.3 (3.1), 225.3 (10.0), and 63.0 (5.2) s for the 22, 27, and 22/27 G needles (P < 0.0001 for comparisons between 27 G and other needles, and P = 0.019 between 22 and 22/27 G needles). Saline was different from mannitol for both measurements and all needles (P < 0.0001).

Conclusions. A 22/27 G tapered spinal needle has similar flow properties to the 22 G needle, despite a 27 G tip.

Keywords: cerebrospinal fluid; lumbar puncture; post-dural puncture headache

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Dural puncture is one of the most common invasive procedures performed in clinical medicine. Post-dural puncture headache (PDPH) is a common and distressing complication, is characterized by severe postural headache, and may be associated also with nausea and vomiting, neck and back pain, tinnitus, and rarely diplopia.¹–³ Symptoms, which are frequently immobilizing, may last from a few days to a few weeks and occasionally for up to a year.² Rare severe complications include subdural haematoma and death.⁶ Iatrogenic neurological symptoms occurring after diagnostic lumbar puncture may become superimposed on the presenting neurological complaints and may confound clinical diagnosis.

Although the pathogenesis of PDPH is not entirely understood, it is associated with the leak of cerebrospinal fluid (CSF) from the dural puncture site.⁵ Accordingly, strategies to prevent PDPH have focused on technical modifications to spinal needles aimed at reducing the size of the dural perforation.⁶,⁷ There is strong evidence that both the use of narrow gauge spinal needles⁶–¹⁵ and the use of pencil-point ‘atraumatic’ needle tips⁸–¹⁰,¹⁵–¹⁹ reduce the incidence of PDPH after dural puncture. These are now Type A recommendations of the American Academy of Neurology.⁹,¹⁰

Dural puncture is most commonly performed by anaesthetists for the provision of spinal anaesthesia and by...
neurologists or paediatricians for diagnostic lumbar puncture. However, the practice of these groups varies widely.\textsuperscript{24–26} Anaesthetists typically use narrow-bore (25–27 G) pencil-point (‘atraumatic’) spinal needles\textsuperscript{6,7,25,26} while diagnostic lumbar puncture is still typically performed using large-bore (20–22 G) spinal needles, frequently with cutting or Quincke tips.\textsuperscript{24–26} Not surprisingly, the incidence of PDPH after diagnostic lumbar puncture is 32–54\%\textsuperscript{91,27} compared with 1–2\% after spinal anaesthesia.\textsuperscript{25} Reasons given for continuing to use large-bore spinal needles for diagnostic lumbar puncture include the shorter time required to equilibrate the CSF pressure when using a manometer and the increased speed in obtaining CSF samples by passive flow.\textsuperscript{91,27,28}

In an experimental study, Carson and Serpell\textsuperscript{28} used an artificial non-pulsatile CSF reservoir to compare different spinal needles for the passive flow rate of CSF and for the time to measure equilibrium CSF pressure by manometry. They concluded that needles smaller than 22 G are not suitable for the measurement of CSF pressure and that 20 G needles are the needles of choice if CSF sampling is to be made.\textsuperscript{28} However, their model used a non-pulsatile reservoir. CSF transmits a pulsatile pressure wave, which would be expected to increase CSF flow from a rigid spinal needle.\textsuperscript{29} We designed a pulsatile CSF model in order to test a spinal needle in use in our institution, which has a wide-bore 22 G shaft with a tapered 27 G pencil-point tip (Temena-Polymedic, Temena International, Carriere-sur-Seine, France).\textsuperscript{30} We tested this needle against a range of spinal needles of different gauge and in two fluids of different viscosity. We hypothesized that in our pulsatile CSF model, such a needle may improve conditions for lumbar puncture; the narrow tip minimizing the incidence of PDPH and the wide shaft reducing the time required to measure CSF pressure manometry and obtain CSF samples.

**Methods**

We designed a pulsatile CSF model (Fig. 1). A 500 ml fluid bag with two entry ports was placed inside an inflatable pressure chamber. The inflating bulb was removed from the pressure chamber and the hose attached via a tracheal tube connector to a Siemens 90°C ventilator. The pressure bag was inflated using the following ventilator paradigm: pressure control ventilation 25 cm H\textsubscript{2}O, rate 80 min\textsuperscript{-1}, PEEP 15 cm H\textsubscript{2}O, I:E ratio 1:2, horizontal waveform mode). This created a pulsatile CSF reservoir with a ‘systolic’ and ‘diastolic’ pressure of about 25/15 cm H\textsubscript{2}O (mean CSF pressure 19 cm H\textsubscript{2}O). The reference port was connected to an optical pressure transducer via a 14 G 3.81 cm long needle. The sampling...
CSF pressure was measured via the spinal needle by traditional manometry, using a disposable plastic manometer (Unomedical A/S DK, Denmark), graduated for the purposes of this study at 0.25 cm intervals. The manometer was fixed at the same vertical height as the CSF reservoir. Before measurement, the stopcock was opened to room air to allow pressure in the manometer to equilibrate to ambient pressure (by the escape of fluid). At time 0, the stopcock was turned connecting the spinal needle to the manometer. Manometer pressure was measured visually every 2 s for at least 120 s, or longer if the pressure was still rising. Manometer pressure was read with a resolution of ± 0.25 cm; data were measured in triplicate for each needle for both fluids.

After the measurement of CSF pressure, we measured the time to obtain 1 ml fluid by passive flow. The spinal needle was disconnected from the manometer and opened to air. A 1 ml glass vial with 0.1 ml graduations was held underneath the hub of the spinal needle. The time to fill 1 ml was measured (using a stopwatch) in triplicate for each needle for both fluids.

We used a range of spinal needles from 18 to 27 G (Table 1). The primary test needle (22/27 G) had a wide-bore 22 G shaft with a tapered 27 G pencil-point tip (Fig. 2). The order of assessment of needles was randomized by computer-generated randomization. Spinal needles and fluids were concealed and numbered and data were recorded by a blinded observer.

Reservoir fluid was at room temperature; the thermostat was set to 20 °C. Two fluids were used in the pulsatile CSF reservoir: 0.9% saline (Teva Pharmaceuticals Industries, Petach Tikva, Israel) and 20% mannitol (Baxter Healthcare, Deerfield, IL, USA). The viscosity and density of 0.9% saline (at 20 °C) is 1.002 mPa s⁻¹ 31 and 1.07 g ml⁻¹ (Information from Baxter Healthcare), respectively. The viscosity and density of CSF (at 37 °C) have been reported as 0.7–1.0 mPa s⁻¹ 32 and 1.0003–1.0007 g ml⁻¹, 33 respectively.

Statistical analysis

All data were recorded in triplicate and are reported as mean [standard deviation (SD)] and 95% confidence intervals (CIs) where appropriate. The measurement of CSF pressure against time was presented graphically for all needles tested. In order to avoid multiple statistical tests, only direct comparisons between the 22, 27, and 22/27 G spinal needles and between the saline and mannitol used in the CSF model were assessed using inferential statistics. We assessed the repeated assessments of CSF pressure over time by repeated-measures analysis of variance (RM-ANOVA), using the polynomial contrast function. The between-subject variables were the fluid in the CSF reservoir (saline vs mannitol) and the spinal needle used. Mauchly’s test for sphericity was used to assess the data and if sphericity assumptions could not be justified, the conservative Greenhouse–Geisser test was used. Bonferroni’s post hoc test was used to distinguish between the 22, 27, and 22/27 G spinal needles. We assessed the time to final CSF pressure equilibration and the time to obtain a 1 ml sample using one-way ANOVA. Bonferroni’s post-hoc test was used to distinguish between the 22G, 27G and 22/27G spinal needles. Statistic analyses were performed using SPSS version 17.0, SPSS Inc., Chicago, IL, USA.

Results

All experiments were performed using the same ventilator settings applied to the inflatable pressure bag enclosing the CSF fluid reservoir. All needles were tested and there were no missing data points. The recorded CSF pressure over time using the manometer connected to the different spinal needles is shown in Figure 3A (saline) and B (mannitol).

Table 1: The length, gauge (external diameter), internal diameter, needle tip and manufacturer details for each needle studied. Data provided by Becton–Dickinson, Franklin Lakes, NJ, USA, and Temena-Polymedic (Temena International)

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Manufacturer</th>
<th>Tip</th>
<th>Internal diameter (mm)</th>
<th>External diameter (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Becton–Dickinson</td>
<td>Quincke</td>
<td>0.864</td>
<td>1.270</td>
<td>88.9</td>
</tr>
<tr>
<td>20</td>
<td>Becton–Dickinson</td>
<td>Quincke</td>
<td>0.623</td>
<td>0.909</td>
<td>88.9</td>
</tr>
<tr>
<td>22</td>
<td>Becton–Dickinson</td>
<td>Quincke</td>
<td>0.432</td>
<td>0.719</td>
<td>88.9</td>
</tr>
<tr>
<td>24</td>
<td>Temena-Polymedic</td>
<td>Sprotte</td>
<td>0.300</td>
<td>0.550</td>
<td>103.0</td>
</tr>
<tr>
<td>25</td>
<td>Becton–Dickinson</td>
<td>Whitacre</td>
<td>0.279</td>
<td>0.516</td>
<td>88.9</td>
</tr>
<tr>
<td>25</td>
<td>Temena-Polymedic</td>
<td>Sprotte</td>
<td>0.300</td>
<td>0.500</td>
<td>103.0</td>
</tr>
<tr>
<td>26</td>
<td>Becton–Dickinson</td>
<td>Whitacre</td>
<td>0.279</td>
<td>0.465</td>
<td>88.9</td>
</tr>
<tr>
<td>27</td>
<td>Becton–Dickinson</td>
<td>Whitacre</td>
<td>0.279</td>
<td>0.426</td>
<td>88.9</td>
</tr>
<tr>
<td>22/27</td>
<td>Temena-Polymedic</td>
<td>Sprotte</td>
<td>Shaft 0.54</td>
<td>Shaft 0.68</td>
<td>103.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tip 0.19</td>
<td>Tip 0.40</td>
<td></td>
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</tbody>
</table>
For clarity, the data for the 22/27 G spinal needle have not been represented in Figure 3A and B but are compared graphically with the 22 and 27 G spinal needles in Figure 3C and D. Comparing the change in CSF pressure measurements over time with RM-ANOVA, between-subject variables were statistically significant for both fluid type (P < 0.0001) and needle gauge (P < 0.0001). Bonferroni’s post hoc tests were statistically significant for the comparison between the 22 and 27 G needles (P < 0.0001) and the 22/27 and 27 G needles (P < 0.0001) but not for the comparison between the 22 and 22/27 G needles (P = 0.06).

The time taken until the manometer was able to record equilibrium ‘CSF pressure’ increased with increasing spinal needle gauge and with increasing spinal fluid viscosity (Fig. 4). The mean (so) time to final equilibrium ‘CSF pressure’ with saline was 40.7 (6.4) s (95% CI 35–57), 108.7 (6.1) s (95% CI 96–121), and 51.3 (4.6) s (95% CI 46–56) for the 22, 27, and 22/27 G needles, respectively. The mean (so) time to equilibrium ‘CSF pressure’ with mannitol were 65.3 (3.1) s (95% CI 59–71), 368.0 (8.0) s (95% CI 358–380), and 103.0 (18.4) s (95% CI 85–120) for the 22, 27, and 22/27 G needles, respectively. Comparing the time to collect a 1 ml sample of CSF with one-way ANOVA, there was a significant effect of the choice of fluid in the CSF reservoir (P < 0.0001). For both fluids, there was a three- to six-fold difference between the 22 vs 27 G needles (both fluids P < 0.0001) and the 22/27 vs 27 G needles (both fluids P < 0.0001). There was also a significant difference between the 22 vs 22/27 G needles for both fluids (saline P = 0.019, mannitol P = 0.023), although this difference was of smaller magnitude than for the other comparisons.

**Discussion**

In this study, we used a pulsatile CSF model to demonstrate that a wide-bore 22 G shaft spinal needle with a tapered 27 G pencil-point tip had CSF flow properties similar to those demonstrated by the 22 G Quincke needle. The equilibrium time for CSF manometry and the time to obtain a 1 ml sample were not different for the two needles, even in the presence of viscous CSF. The 22/27 G spinal needle therefore should be as practical to use as the 22 G spinal needle (in terms of the time required for CSF pressure manometry...
and CSF sampling), but with a lower incidence and severity of PDPH. This was in contrast to the regular 27 G spinal needle, where the mean time required to measure CSF pressure by manometry (108 s) and the mean time required to obtain a 1 ml CSF sample (225 s) were both too long for routine clinical diagnostic use.

CSF is a pulsatile fluid and accordingly we chose to use a pulsatile CSF model in this study. Previous studies have used non-pulsatile, artificial CSF chambers to assess flow rates through spinal needles of different design,28 34–37 either to determine the time until CSF flashback34–37 (an important landmark confirming intrathecal placement) or for CSF sampling time.28 Unlike pulsatile flow in an elastic-walled tube (e.g. aorta), spinal needles are rigid non-elastic tubes. The physical properties of pulsatile flow in a rigid tube have been described.29 In a rigid tube, systolic peak pressures are transmitted instantaneously through the needle without being absorbed. These higher systolic pressure peaks cause an additional 'squirt' of CSF to be expelled from the needle at each systole. In non-pulsatile flow, where flow is driven by only a static pressure, this does not happen. As a consequence, flow is expected to be greater in the pulsatile state and the use of a non-pulsatile CSF chamber may significantly under-estimate the passive flow of CSF through spinal needles.

There are several limitations to this study. We did not use a range of different CSF pressures and the pressure chosen was moderately high (mean 19 cm H2O), compared with 12–15 cm H2O normally encountered with the patient lying in the lateral position. Increased CSF pressure will increase the passive flow of CSF and reduce the time to collect CSF samples. This potential limitation does not diminish the relative difference observed in CSF sampling times between different spinal needles. Importantly, the slightly increased

Fig 3 CSF pressure measured by manometry every 2 s for 120 s for a range of spinal needles (see Table 1 for details of needles). The equilibration time for the spinal needles increased as the internal diameter decreased. The equilibration time increased with increasing fluid viscosity, as can be seen by comparing 0.9% sodium chloride (A and C) vs 20% mannitol (B and D). (A and B) The CSF manometry pressure over time for all spinal needles assessed in this study. Coloured lines represent mean data; SDs have been omitted for the sake of clarity from these graphs. (C and D) The CSF manometry pressure over time for the three spinal needles directly compared in this study: 22, 27, and the tapered 22/27 G spinal needle (22 G shaft, 27 G pencil-point tip). Data are presented as mean (SD) based on triplicate measures for each spinal needle. The change in CSF pressure measurements over time for both the 22 and 22/27 G needles was significantly different from the 27 G needle (RM-ANOVA, *P < 0.0001) but not significantly different from each other.
CSF pressure in our set-up should not have affected the time to equilibrium CSF pressure by manometry as the increased rate of filling the manometry tubing is exactly offset by the increased vertical height that needs to be filled. Another limitation was that the CSF was maintained at room temperature, and as a consequence, the fluids used had a slightly higher viscosity than would have been observed at body temperature. These limitations partly offset each other as regards possible effects on the time to collection of CSF samples. Nevertheless, the main observations are not affected by these concerns, specifically (i) the time to measure equilibrium CSF pressure and the time to collect a 1 ml CSF sample are profoundly affected by the gauge of the spinal needle and to a lesser degree by the viscosity of the CSF fluid and (ii) the flow properties of the 22/27 G needle are similar to those of the 22 G needle.

A further potential limitation is that the needles tested differed in respects other than gauge, in particular the needle tip orifice area and the length of the needle (Table 1). However, when compared with gauge, the effects of both orifice area and needle length are relatively minor. The lack of effect of orifice area was illustrated clearly in a published study where the area of the side orifice was reduced from 1.7 × 0.32 to 0.32 × 0.32 mm with no effect on observed flow rates. In that study, based on both theoretical calculations and observational data, it was demonstrated that only by reducing the orifice size below the cross-sectional area of the needle would flow rates be affected. None of the needles used in our study had orifice sizes smaller than needle cross-sectional area. Regarding needle length, from Poiseuille’s law, flow rates are proportional to the fourth power of needle radius and inversely proportional to only the first power of needle length. In turbulent flow, the dependence on needle radius is even greater (fifth power of radius). Clearly, when comparing the 27 and 22/27 G needles, the 14.1 mm increase in length of the 22/27 G needle would be expected to reduce flow rates to some degree, but this would be expected to be dwarfed by the effect due to increased shaft radius. Thus, it may not be surprising that despite the different needle lengths and orifice designs of the needles in this study, it was the diameter of the needle shaft that seemed to have the overwhelming impact. The 22/27 G needle had flow properties between those of the 22 and 24 G needles and markedly different from those of the 27 G needle. Had the 22/27 G needle been of the same length as the 22 G needle used, it is likely that the similarity in flow to the 22 G needle would have been even closer.

There are two conflicting demands on the design of a spinal needle. With reducing spinal needle gauge (increasing needle diameter), the rate of CSF flashback, the CSF sampling rate, and the rate of reaching equilibrium CSF pressure by manometry are all increased. A 22 G needle is probably the smallest...
needle compatible with the flow rates needed for routine diagnostic lumbar puncture. On the other hand, with increasing spinal needle gauge, the incidence of PDPH reduces. For 22 G spinal needles, the PDPH rate is 25–54% (cutting) and 3% (pencil point) for 26 G needles: 9.6% (cutting) and 2.7% (pencil point); and for 27 G needles: 1.5–1.7%. The combination of a 27 G pencil-point tip and a wide-bore 22 G shaft may be an ideal combination for a spinal needle for diagnostic lumbar puncture. There were minor differences in flow properties between the 22/27 and 22 G spinal needles, particularly a 22 s increase in the time to collect a 1 ml saline sample. However, it may be questioned whether this would justify the higher PDPH rates associated with a 27 G dural puncture hole.

We have used over 30 000 of these 22/27 G tapered spinal needles over the past 14 yr in our institution for the provision of spinal anaesthesia and analgesia in a mixed surgical and obstetric population. Most of these anaesthetics were administered by junior residents and no serious complications have occurred (with the exception of one needle that fractured in subcutaneous tissue requiring removal under fluoroscopy). The incidence of PDPH is below 1% in our obstetric population in patients receiving the 22/27 G tapered spinal needle. Although the learning curve may be longer and the cost significantly greater for 22/27 G tapered spinal needles when compared with conventional 22 G spinal needles, these are probably justified if they can reduce the incidence of an immobilizing headache after diagnostic lumbar puncture from 25–54% (or even 7–8%) down to 1.5–1.7%. As the authors of the American Academy of Neurology report wrote, quoting Tourtellotte and colleagues (writing in the neurology literature nearly 50 yr ago): ‘If patients undergoing an LP for diagnostic purposes were treated like patients undergoing spinal anaesthesia, the frequency of PDPH could be markedly reduced’.

In summary, this study describes the use of a pulsatile CSF model to assess the equilibration time for pressure manometry and CSF sampling rates through a range of spinal needles of different gauge and with fluids of different viscosity. A 22/27 G tapered spinal needle (with a 22 G shaft and a narrow 27 G pencil-point tip) has flow properties similar to those of the 22 G spinal needle but creates a 27 G rather than a 22 G puncture hole in the dura. This would be expected to reduce the incidence and severity of PDPH, typically associated with large-bore needles.

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Declaration of interest

None declared.

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