Pressures generated *in vitro* during Stabident intraosseous injections

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Abstract

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Aim To test the hypothesis that the Stabident intraosseous injection is a potentially high-pressure technique, which carries serious risks of anaesthetic cartridge failure.

Methodology A standard Astra dental syringe was modified to measure the internal pressure of local anaesthetic cartridges during injection. Intra-cartridge pressures were measured at 1 s intervals during slow (approximately 15 s) and rapid (<10 s) injections of 2% Xylocaine with 1 : 80 000 adrenaline (0.25 cartridge volumes) into air (no tissue resistance), or into freshly prepared Stabident perforation sites in the anterior mandible of freshly culled young and old sheep (against tissue resistance). Each injection was repeated 10 times over 3 days. Absolute maximum pressures generated by each category of injection, mean pressures at 1 s intervals in each series of injections, and standard deviations were calculated. Curves of mean maximum intra-cartridge pressure development with time were plotted for slow and rapid injections, and one-way ANOVA ($P < 0.05$) conducted to determine significant differences between categories of injection.

Results Pressures created when injecting into air were less than those needed to inject into tissue ($P < 0.001$). Fast injection produced greater intra-cartridge pressures than slow delivery ($P < 0.05$). Injection pressures rose more quickly and to higher levels in small, young sheep mandibles than in larger, old sheep mandibles. The absolute maximum intra-cartridge pressure developed during the study was 3.31 MPa which is less than that needed to fracture glass cartridges.

Conclusions Stabident intraosseous injection conducted in accordance with the manufacturer's instructions does not present a serious risk of dangerous pressure build-up in local anaesthetic cartridges.

Keywords: intraosseous, local anaesthetic, pressure, Stabident.

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Introduction

Supplementary injections are often needed to profoundly anaesthetize irreversibly inflamed pulps (Meechan 2002). These control pain by increasing drug dose, blocking variant neural pathways or simply concussing sensory nerves. Some are high-pressure methods which may cause anaesthetic cartridges to fail (Meechan & McCabe 1986, Meechan *et al.* 1990) although detailed evidence is often lacking.

Intraosseous injection is an effective adjunct in emergency endodontics (Nusstein *et al.* 2003), and the Stabident system (Fairfax Dental Inc., Miami, FL, USA) is one of the proven commercial designs (Nusstein *et al.* 1998, Gallatin *et al.* 2003). This system delivers local anaesthetic solution into cancellous bone with a standard dental syringe and ultra-short (6 mm), 27-gauge needle. Cortical perforators and needles are size-matched (Ramlee & Whitworth 2001) to avoid backflow and loss of drug during injection into a low-compliance tissue.

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The manufacturer's instructions recommend slow delivery of one quarter cartridge of anaesthetic solution, but make no observations on the risks of pressure build-up during injection into a closed system.

This study was designed to test the hypothesis that the Stabident intraosseous technique is a potentially high-pressure technique, which carries serious risks of anaesthetic cartridge failure.

Materials and methods

Development of a system to measure the internal pressure of dental local anaesthetic cartridges during injection

Our experimental system was based on the modified Astra syringe model of Maita & Horuichi (1984) (Fig. 1).

Briefly, a standard Astra (AstraZeneca, Macclesfield, UK) dental syringe was modified by the addition of a 20-gauge stainless steel needle inserted and secured through the housing of the barrel (Department of Engineering, University of Newcastle, UK). This was connected to a pressure transducer [RDP Electronics, Wolverhampton, UK; pressure range 0–1000 psi (0–6.89 MPa)] which was mounted on the syringe barrel. This in turn was connected to a microprocessor-based strain amplifier (E525 Cypher; RDP Electronics), fitted with a standard RS232 interface for communication with the Hyperterminal programme for Windows 95 (Hilgraeve Inc., Monroe, MI, USA), allowing the capture of pressure readings from the strain amplifier and pressure transducer. The pressure transducer and strain amplifier were calibrated by the supplier prior to delivery.

Pressure measurement

Standard local anaesthetic cartridges [2.2 mL of 2% Xylocaine with 1 : 80 000 adrenaline (AstraZeneca)] were marked to indicate 0.25 cartridge volumes before loading into the modified Astra syringe (AstraZeneca) carrying a Stabident ultra short (6 mm) 27-gauge needle. A series of pressure recordings was made during the injection of 0.25 cartridge volumes into:

1. Air (no tissue resistance),
2. Fresh Stabident perforation sites in the dentate anterior mandible of:

(a) two freshly culled young (approximately 1 year old) sheep,
(b) two freshly culled old (approximately 4 years old) sheep.

New puncture holes, needles and cartridges were employed for each injection.

The pressures which developed in the syringe cartridge were recorded at 1 s intervals during a series of 10 slow (approximately 15 s) and 10 rapid (as rapidly as possible; <10 s) injections into air and into sheep mandibles.

Injections in each series were spread over 3 days to avoid operator fatigue and to allow dispersal of local anaesthetic within the specimen. All injections were made by a single, female investigator (RAMR). Local anaesthetic cartridges employed in this study were stored and administered at room temperature. Sheep mandibles were stored under refrigeration (4 °C) and allowed to equilibrate to room temperature for 2–3 h before injection.

Analysis

The absolute maximum pressures generated by each series of injections, mean pressures and standard

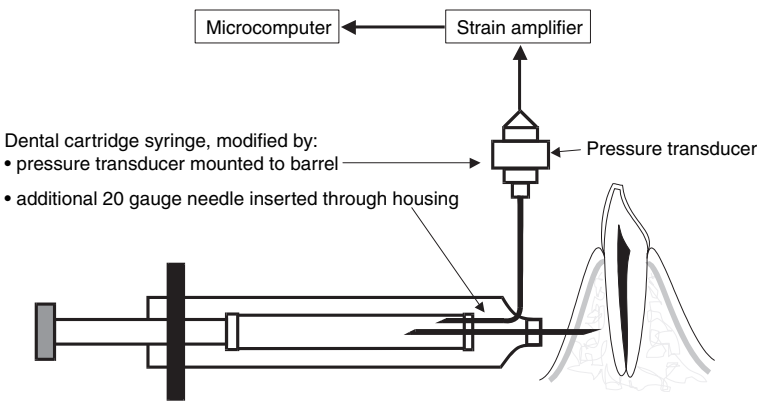

Figure 1 Schematic diagram of local anaesthetic pressure testing system.

deviations were calculated with Microsoft Excel for Windows XP. Curves of mean maximum intra-cartridge pressure development with time were plotted for slow and rapid injections in Microsoft Excel, and one-way ANOVA (confidence interval $P < 0.05$) conducted to determine significant differences between the various categories of injections.

Maximum pressure recordings were compared with published Weibull curves of local anaesthetic cartridge failure (Meechan *et al.* 1990) to provide insight into the likelihood of system failure resulting from the intra-cartridge pressures generated during use of the Stabident intraosseous method.

Results

The mean maximum and absolute maximum intra-cartridge pressures generated during injections into air, and sheep mandibles are shown in Table 1.

Maximum and mean maximum intra-cartridge pressures were always greater during injection into tissue compared with air, where there was no external resistance ($P < 0.001$).

Table 1 Pressures generated during injection (MPa) ($n = 10$)

Type of injection	Mean maximum pressure (MPa) in series (SD)	Absolute maximum pressure (MPa) in series
Slow, into air	0.05 (0.01)	0.07
Rapid, into air	0.47 (0.08)	0.56
Slow, young sheep	1.67 (0.45)	2.16
Rapid, young sheep	2.78 (0.53)	3.31
Slow, old sheep	1.40 (0.17)	1.64
Rapid, old sheep	2.38 (0.30)	2.83

Rapid injection always generated higher absolute and mean maximum intra-cartridge pressures than their respective slow injection ($P < 0.05$). There were, however, no statistically significant differences between the mean maximum and absolute maximum intra-cartridge pressures generated during slow injection into young or old sheep mandibles, or rapid injection into young or old sheep mandibles.

Curves illustrating the development of intra-cartridge pressure with time for slow injections are shown in Fig. 2. Slow injection into air (no tissue resistance) created a small rise in intra-cartridge pressure, which peaked after approximately 4 s and remained steady throughout the injection period. All injections into tissue were associated with similar profiles of pressure increase, peaking between 7 and 10 s, at levels between 1.4 and 1.68 MPa, before declining towards the end of the injection.

Greater variation was seen amongst the rapid injections (Fig. 3). Injecting as quickly as possible without tissue resistance resulted in a pattern of pressure behaviour which was similar to the slow injection. Intra-cartridge pressure rose to a peak at approximately 5 s, and remained relatively constant until the end of the injection period.

Sharp increases in pressure were noted during the first 4–6 s of injection against issue resistance, with both the rate of development and peak value being greatest in the relatively small young sheep mandible.

Discussion

Pressure generation is relevant to the effectiveness and safety of some local anaesthetic methods (List *et al.* 1988, VanGheluwe & Walton 1997). The intrali-

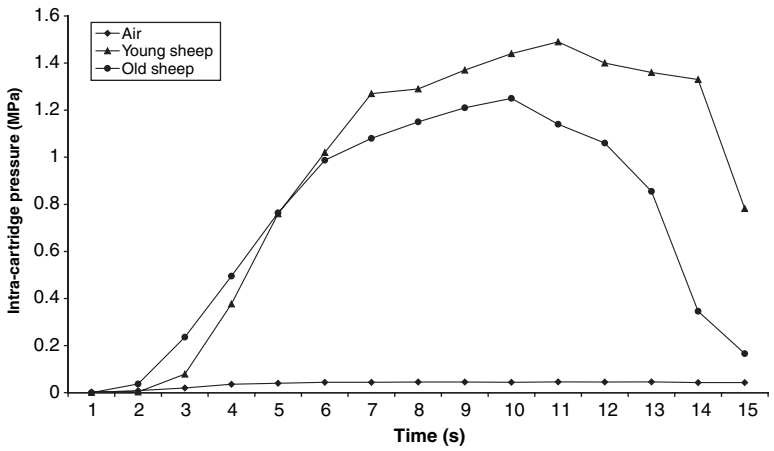

Figure 2 Mean maximum intra-cartridge pressure (MPa) versus time (s), slow injection.

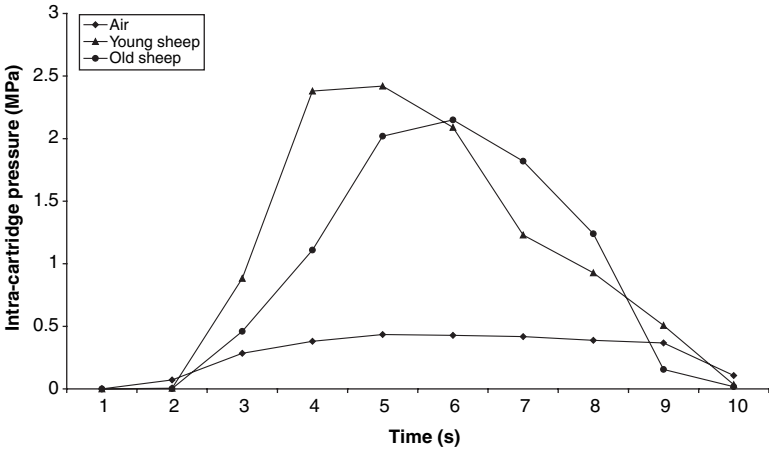

Figure 3 Mean maximum intra-cartridge pressure (MPa) versus time (s), rapid injection.

gamentary injection may, for example, generate high pressures, especially in combination with commercial pressure syringes (Walmsley *et al.* 1989). Few data have been available on pressures generated during intra-osseous injection where solution is deposited into a low-compliance tissue space.

A number of researchers have described systems for measuring pressure in local anaesthetic systems (Pashley *et al.* 1981, Maita & Horuichi 1984, Rieu *et al.* 1989, Walmsley *et al.* 1989). Our specific interest was intra-cartridge pressure which was readily measured by the Maita & Horuichi (1984) method as described.

Simulation models are widely employed in biomedical research. The limited availability of whole dentate human cadaver mandibles necessitated the use of an alternative, medium-sized mammalian model in the current research. Fresh, dentate ovine mandibles were readily sourced, and only the anterior mandible was utilized, where tooth shape and arrangement was comparable to the human. We are unable to speculate on the comparability of our own results with those likely from injection into the jaws of living creatures.

Despite considerable effort to standardize injections, some degree of operator variability was inevitable. This was particularly so for rapid injections, necessitating frequent breaks and spreading injections over 3 days. It was rare for even the slow injections to be given absolutely smoothly and consistently due to the behaviour of the cartridge rubber plunger, which typically moved along the cartridge barrel with a juddering motion. Even a mechanical syringe driver could not deliver truly smooth injections. However, the injections were clinically realistic and the standard deviations indicate an acceptable level of consistency.

Multiple cortical perforations and injections did not result in any clear pattern of pressure reduction or increase as the series progressed. Fluid was not noted to emerge through perforation sites.

This investigation provides some of the first evidence on pressures generated in local anaesthetic cartridges during the use of contemporary intraosseous injection techniques in the mandible. Pressure recordings were comparable with those of Pashley *et al.* (1981), who reported maximum injection pressures into the jaws of dogs in the range between 1.93 and 3.24 MPa. It was noted that injection pressures were highest in less distensible tissues, with the intra-osseous injection developing higher maximum pressure (2.88 MPa) than incisive papilla (2.43 MPa), periodontal ligament (2.35 MPa), hard palate (1.51 MPa) and intrapulpal (1.19 MPa) injections. Other researchers have noted even higher intra-cartridge pressure generation (4 MPa) during *in vitro* simulation of intraligamentary and intraosseous injections. By contrast, Shepherd *et al.* (2001) measured the intrabony pressure increase during injection of swine mandibles, and reported pressure increases an order of 10 lower than the lowest intra-cartridge pressure during slow injection against no resistance recorded in the present study.

Some of this inconsistency must reflect details of protocol, including the injection recipient, the volume of anaesthetic delivered, the rate of deposition, the measuring system, the temperature of the cartridge (Meechan *et al.* 1995) and the site measured. In addition, the length and gauge of the needle influences pressure generated in dental local anaesthetic cartridges (Meechan & McCabe 1986). It can be inferred that local anaesthetic injection systems do not develop consistent increases in pressure throughout. In the

present work, the small mandibles of young sheep were associated with more rapid and higher peak pressure of injection than larger, mature sheep. There is a need to standardize methods for evaluating this important element of local anaesthetic delivery and safety.

Sowray (1983) stated that anaesthetic cartridges were designed to resist approximately 4.1 MPa of pressure. Previous investigations (Meechan & McCabe 1986) have shown that the range of pressures causing fracture of 2.2 mL Xylocaine (AstraZeneca) dental anaesthetic cartridges of the type employed in this study were beyond this range (5.51–15.7 MPa).

The maximum pressures encountered, even when injections were administered as rapidly as physically possible, were no higher than 3.31 MPa. It is important to point out that the operator in this study was female. A previous investigation has shown that male operators can generate greater pressures than females (Maita & Horuichi 1984). In that study (Maita & Horuichi 1984), males could produce approximately 28% greater maximum force. If the forces recorded in the present study were increased by 28%, this is still below that needed to fracture glass cartridges. It can be concluded, therefore, that glass Xylocaine (AstraZeneca) anaesthetic cartridges were at no significant risk of fracture during intraosseous injection by the Stabident method. The forces reported in this investigation are less than that reported during intraligamentary injections (Walmsley *et al.* 1989). Intraligamentary injections are considered a type of intraosseous anaesthesia (Smith & Walton 1983). Although intraligamentary anaesthesia may be considered an intraosseous injection from a physiological point of view, the true intraosseous technique differs in a mechanical sense in that less force is generated in the cartridge with the latter technique.

Plastic local anaesthetic cartridges are known to fail between 3.03 and 6.89 MPa. The peak intra-cartridge pressure developed during slow intraosseous injection was <1.67 MPa, thus plastic cartridges are at little risk of failure during Stabident injections when the injection is given slowly. Examination of Weibull distribution curves (Meechan *et al.* 1990) suggests that if intraosseous injection was given very rapidly (peak pressure 3.31 MPa), there may be a 10–15% risk of plastic cartridge failure. Plastic cartridges fail due to distortion of the cartridge plunger with loss of anaesthetic solution, rather than dangerous failure of the cartridge walls (Meechan *et al.* 1990). It can be suggested that plastic and glass anaesthetic cartridges may be used with safety in the Stabident intraosseous technique, provided that the manufacturer's instructions for slow injection are followed.

Within the limitations of this study, the working hypothesis that the Stabident intraosseous technique is a potentially high pressure technique which carries serious risk of anaesthetic cartridge failure was disproved.

Conclusions

Stabident intraosseos injection conducted in accordance with the manufacturer's instructions does not present a serious risk of dangerous pressure build-up in local anaesthetic cartridges. It is important to note that the recommended needle length and gauge was used. As the forces produced within the cartridge will increase with longer and narrower needles (Meechan & McCabe 1986) the present results should not be extrapolated to cover all intraosseous injections.

References

Gallatin J, Reader A, Nusstein J, Beck M, Weaver J (2003) Comparison of two intraosseous anesthetic techniques in mandibular posterior teeth. *Journal of the American Dental Association* **134**, 1476–84.

List G, Meinster F Jr, Nery EB, Prey JH (1988) Gingival crevice fluid response to various solutions using the intraligamentary injection. *Quintessence International* **19**, 559–63.

Maita E, Horuichi H (1984) Measurement of pressures developed in the syringe during dental infiltration anaesthesia. *British Dental Journal* **156**, 399–400.

Meechan JG (2002) Supplementary routes to local anaesthesia. *International Endodontic Journal* **35**, 885–96.

Meechan JG, McCabe JF (1986) A model for investigating the probability of fracture of dental local anaesthetic cartridges. *British Dental Journal* **160**, 326–8.

Meechan JG, McCabe JF, Carrick TE (1990) Plastic dental local anaesthetic cartridges: a laboratory investigation. *British Dental Journal* **169**, 54–6.

Meechan JG, Donaldson D, Kotlicki A (1995) The effects of storage temperature on the resistance to failure of dental local anaesthetic cartridges. *Journal of the Canadian Dental Association* **61**, 143–8.

Nusstein J, Reader A, Nist R, Beck M, Meyers WJ (1998) Anesthetic efficacy of the supplemental intraosseous injection of 2% lidocaine with 1:100000 epinephrine in irreversible pulpitis. *Journal of Endodontics* **24**, 487–91.

Nusstein J, Jennedy S, Reader A, Beck A, Beck M, Weaver J (2003) Anaesthetic efficacy of the supplemental X-tip intraosseous injection in patients with irreversible pulpitis. *Journal of Endodontics* **29**, 724–8.

Pashley EL, Nelson R, Pashley DH (1981) Pressures created by dental injections. *Journal of Dental Research* **60**, 1742–8.

Ramlee RA, Whitworth J (2001) Dimensions of Stabident intraosseous perforators and needles. *Journal of Endodontics* **27**, 581–3.

Rieu R, Bouvier C, Fuseri J, Proust JP (1989) Injection pressure of anesthetics using 30-gauge needles with or without side perforation. *Journal of Endodontics* **15**, 453–6.

Shepherd PA, Eleazer PD, Clark SJ, Scheetz JP (2001) Measurement of intraosseous pressures generated by the Wand, high pressure periodontal ligament syringe and Stabident system. *Journal of Endodontics* **27**, 381–4.

Smith GN, Walton RE (1983) Periodontal ligament injection: distribution of injected solutions. *Oral Surgery, Oral Medicine, Oral Pathology* **55**, 232–8.

Sowray JH (1983) Intraligamental syringes. *Dental Practice* **21**, 1–2.

VanGheluwe J, Walton R (1997) Intrapulpal injection: factors related to effectiveness. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **83**, 38–40.

Walmsley AD, Lloyd JM, Harrington E (1989) Pressures produced *in vitro* during intraligamentary anaesthesia. *British Dental Journal* **167**, 341–4.