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ORIGINAL ARTICLE

Movement control during aspiration with different injection systems via video monitoring—an in vitro model

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Abstract

Objectives The aim of the present study was an evaluation of movement during double aspiration by different manual syringes and one computer-controlled local anesthesia delivery system (C-CLAD).

Materials and methods With five different devices (two disposable syringes (2, 5 ml), two aspirating syringes (active, passive), one C-CLAD), simulation of double aspiration in a phantom model was conducted. Two experienced and two inexperienced test persons carried out double aspiration with the injection systems at the right and left phantom mandibles in three different inclination angles ($n = 24 \times 5 \times 2$ for each system). 3D divergences of the needle between aspiration procedures (mm) were measured with two video cameras.

Results An average movement for the 2-ml disposal syringe of 2.85 mm (SD 1.63), for the 5 ml syringe of 2.36 mm (SD 0.86), for the active-aspirating syringe of 2.45 mm (SD 0.9), for the passive-aspirating syringe of 2.01 mm (SD 0.7), and for the C-CLAD, an average movement of 0.91 mm (SD 0.63) was seen. The movement was significantly less for the C-CLAD compared to the other systems ($p < 0.001$). The movement of the needle in the soft tissue was significantly less for the C-CLAD compared to the other systems ($p < 0.001$).

Conclusions A difference in involuntary movement of the syringe could be seen in comparison between manual and C-CLAD systems. Launching the aspiration by a foot pedal in computer-assisted anesthesia leads to a minor movement.

Clinical relevance To solve the problem of movement during aspiration with possibly increased false-negative results, a C-CLAD seems to be favorable.

Keywords Aspiration · Inferior alveolar nerve block · Local anesthesia · C-CLAD · Deviation

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Introduction

By rapid absorption, a local anesthetic may yield high drug concentrations in the blood [1]. Both the central nervous system and the cardiovascular system are particularly sensitive to high plasma concentrations of local anesthetics. In addition, epinephrine as adjunct has an additional influence on cardiovascular function [2, 3] like changes in heart rate, blood pressure, and cardiac dysrhythmia [4–7].

Due to this toxicity, an intravascular injection during inferior alveolar nerve block (IANB) can lead to severe cardiovascular and/or central nervous effects leading—in the worst case—to a lethal result [2, 8, 9]. Therefore, aspiration before injection of a local anesthetic is recommended in order to determine whether the needle tip lies within a blood vessel. If blood appears in the syringe, the needle tip is in an intravascular position. If the needle tip is located within a blood vessel and the negative pressure pulls the wall of the vessel against the bevel of the needle, a false-negative result of the aspiration is possible. Other reasons for a wrong negative aspiration may be a small aspiration volume or a small diameter of the needle [10, 11]. Another possible cause is the collapse of a small vessel (with a caliber of under 1.5 mm) due to excessively intense aspiration [10, 11]. Therefore, in order to minimize the risks of a false-negative aspiration with a possible intravasal injection, an aspiration in at least two planes before injection is required [9, 12, 13]. Even though, IANB has an incidence of positive aspiration from 4 to 22 % [14, 15]. In children, the risk of intravascular injection is even higher when compared to adults [16, 17].

The aspiration in two planes is a dynamic process in which the hand makes involuntary movements. This iatrogenic problem may also lead to false-negative results. Each syringe system has a different kind of aspiration. The dentist has the choice between active aspiration syringes like disposable plastic-made syringes, syringes with a thumb ring, passively aspirating syringe systems, or a computer-controlled local anesthesia delivery system (C-CLAD) with an additional possibility for active aspiration, mostly induced by a foot pedal. An association between involuntary movements during aspiration and the type of used syringe system is possible. To our knowledge, this important issue has not been examined so far.

Therefore, it was hypothesized that involuntary movements while aspirating in two planes are influenced by different syringe systems, different positioning of the patient, differences when injecting in the left and right mandible as well as individual movements of persons during the injection process. All experiments were conducted in an in vitro phantom head model.

Material and methods For the simulation of IANB, a phantom model head (KAVO®, Biberach/Riß, Germany) with jaw models for intraoral injections (model *AG-3IB*, Frasaco®, Tettnang, Germany) was used. The phantom model head was set in three different angles of inclination (0°, 25°, and 45° backward) to simulate possible different positions of a patients' head in a dental chair. Test persons were two experienced dentists (>1000 IANBs) and two dental students (<25 IANBs). The used syringe systems were two disposable plastic-made syringes with a capacity of 2 ml (Braun, Melsungen, Germany) and 5 ml (Becton, Dickinson and Company, Franklin Lakes, NJ, USA), an active aspiration syringe (Uniject®, Aventis, Germany), a passive aspiration syringe (Aspiject®, Ronvig A/S, Daugaard, Denmark) as well as a computer-controlled local anesthesia delivery system (C-CLAD; The Wand®/STA (Single Tooth Anesthesia); Milestone Scientific, Inc., Livingston, NJ, USA; Fig. 1). For the two disposable plastic-made syringes and the active aspiration syringe, pulling the plunger back and then encompassing in the second level starts aspiration. In the passively aspirating syringe, the aspiration is initiated by pushing a ring, which is placed on the syringe corpus. When using C-CLAD, the implementation of the aspiration and the injection is started by a foot pedal that is situated at the base station of the system.

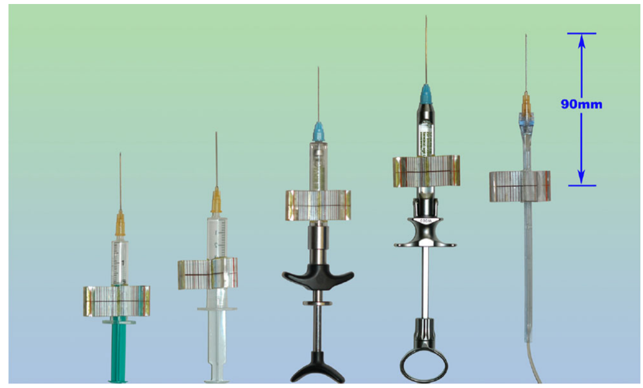

Fig. 1 All five syringe systems with installed millimeter plates. The space of the cannula needle to the measuring point was adjusted to 90 mm

Treatment protocol

For IANB, aspiration in two planes with encompassing of the hands was used. After the first aspiration, the barrel of the syringe was rotated about 45° for the second aspiration. In brief, the needle was inserted into the tissue until contact to the internal surface of the ramus of the mandible. In the 2- and the 5-ml disposal syringes, the index finger and middle finger were at the corpus of the syringe and the thumb was on the piston. The leading hand (right-handed, right hand) rested in this position until the other hand took the corpus of the syringe and fixed it in this position. With the leading hand, the test person took the end of the flexible piston while the syringe was held with the left hand. While pulling back the piston, a negative pressure was created and the first aspiration took place. Afterwards, the barrel of the syringe was turned about 45° for second aspiration. For the thumb ring syringe, the index finger and the middle finger were at the indentations at the corpus; the thumb applied in the ring at the end of the syringe before pulling the piston in the contrary direction of the injection launched the aspiration. Likewise, second aspiration of the syringe was performed. When using the self-aspirating system, the fingers of the right hand held the syringe in injection position. The left thumb launched the aspiration by releasing a ring. The right hand stayed the whole time in injection position so that after aspiration, the injection could be initiated. During aspiration with the C-CLAD, the right hand held the syringe and aspiration was started by foot pedal. Equally, the second aspiration started by foot pedal.

Twenty-four aspirations for each syringe system and each side of the mandible (24 × 5 × 2) were carried out for the evaluation in order to investigate a possible influence of the syringe system. 24 × 5 tests with a positioning angle of 0°, 24 × 5 tests with a positioning angle of 25°, and 24 × 5 tests with a positioning angle of 45° were conducted. Half of the tests (12 × 5 × 2 at each inclination) were conducted by experienced test persons and half of the tests by less-experienced test persons.

Measurement of syringe deviation

The deviation during the aspiration in two planes was measured with two video cameras. On each syringe, plates with a millimeter scale were attached. The plates were used to obtain reproducible measuring points in order to calculate the movements of the syringes (Figs. 1, 2, and 3).

Camera C1 (Fig. 3), which recorded the test vertically from above, showed the movement in the x- and z-axes. Camera C2, which was positioned laterally, provided the information about the movement in the x- and y-axes. The positioning of the camera in right angles to each other provided acquisition of the deviation in space (ds) from the reference point with the following formula for each syringe system:

$$\mathrm{Ds} = \sqrt{x1^2 + y1^2 + z1^2}.$$

From the reference point to the point of penetration in the mandible model, the mean distance was 90 mm. The deviation in the soft tissue (dt) in the time after the first and before the second aspiration was calculated with this formula:

$$Dt = \sqrt{x2^2 + y2^2 + z2^2}\ .$$

Statistics

To evaluate the influence of the different syringe systems and the influence of different positioning of the "patient," of the adjacent sides of the mandible, of the experience, and of the individual influence of the test persons on the movements during aspiration, an one-way analysis of variance (ANOVA) with Tukey simultaneous post hoc test was conducted to compare groups. Due to multiple testing, p values <0.01 were termed significant. The analyses were conducted using SPSS version 15.0 (SPSS, Chicago, IL, USA).

Results

Influence of the syringe system

With the 2-ml syringe, an average deviation in space of 2.84 mm (standard deviation (SD) 1.63) with the 5-ml disposal syringe of 2.36 mm (SD 0.86) and with the thumb ring syringe of 2.45 mm (SD 0.9) was seen.

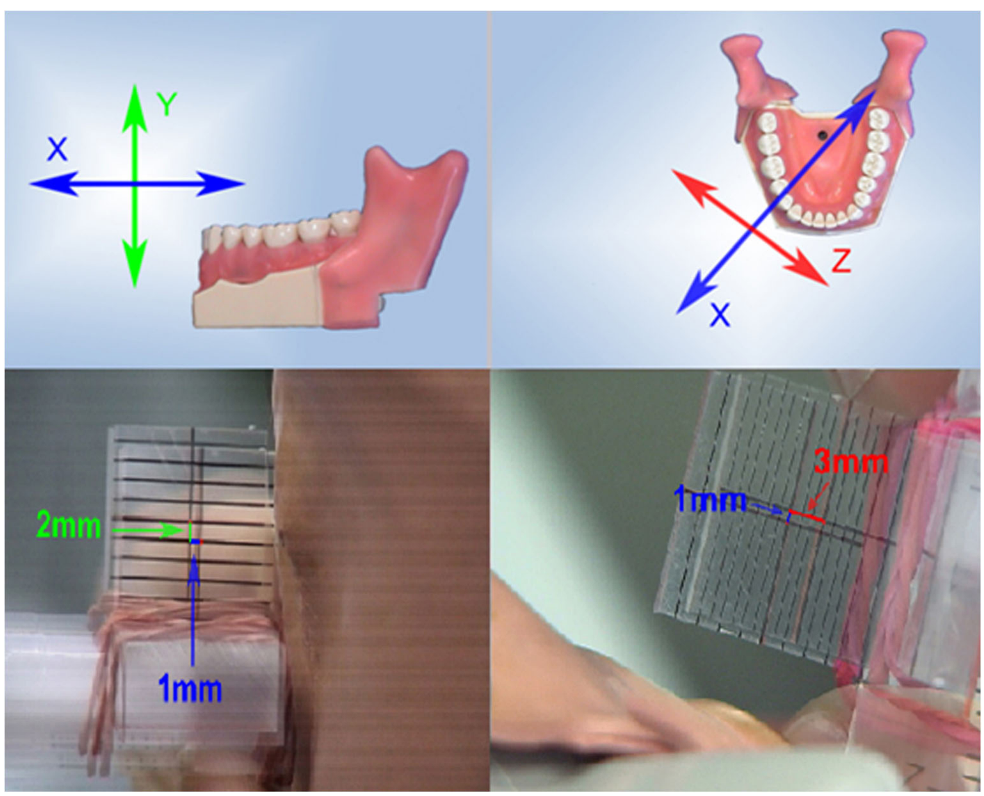

Fig. 2 There were three spatial axes (x-, y-, and z-axes) on which the syringe was able to move at time-zero, which marks the beginning of the aspiration sample. The x-axis passes axially through the longitudinal axis of the syringe. The sagittal plane represented by the y-axis depicts the fact whether the syringe is moving cranially or caudally. The z-axis passes transversally. As the recordings were only of a two-dimensional view, the information about the movement in the third axis were extracted from the evaluation of the second camera's recordings. Depending on which camera recordings were played, two axes each were directly obtained

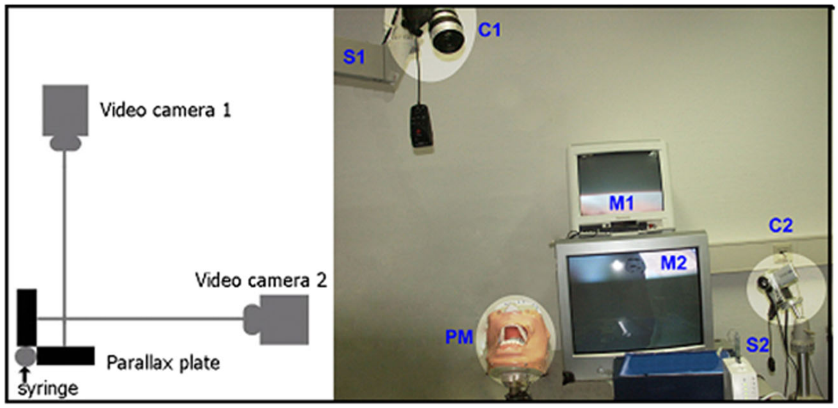

Fig. 3 Test-setup, *PM* phantom model, *C1*: camera 1 which vertically records the test from above, *S1*: tripod for alignment of camera 1, *M1*: TV for video of camera 1, *C2*: camera 2 which records the test horizontal from the side, *S2*: tripod for alignment of camera 2, *M2*: TV for video of camera 2

The deviation of the active aspirating syringe was 2.01 mm (SD 0.7). Only the C-CLAD aspiration had a significant lower deviation compared to the four other syringes with a mean deviation of 0.91 mm (SD 0.63) (each $p < 0.001$) (Fig. 4).

Positioning of the phantom model

For an angle of 0°, a total mean movement of 2.00 mm (SD 0.91), for an angle of 25°, a mean movement of 2.36 mm (SD 1.54), and for an angle of 45°, a movement 1.98 mm (SD 1.0) was seen. The difference between the positioning angles was not statistically significant (each $p > 0.3$). Again, when comparing the syringe systems in dependence to the positioning of the mandible, significant differences were seen for C-CLAD in comparison to the other systems only (each $p < 0.001$).

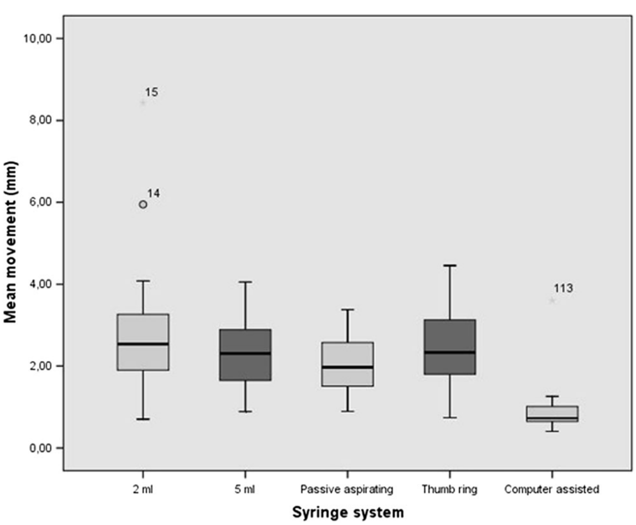

Fig. 4 Boxplots comparing the deviation of the five syringe systems (average values of all three axes; data in mm)

Differences between mandible sides

For the left side, a mean of 2.15 mm (SD 1.38) and for the right side, a mean movement of 2.07 mm (SD 0.98) was seen. The differences between mandible sides were neither statistically significant in total ($p = 0.715$) nor when comparing the syringe systems ($p = 0.65$).

Experience of the test persons

For the experienced test persons, a mean of 2.2 mm (SD 1.13) and for the less experienced, a mean movement of 2.02 mm (SD 1.25) was seen. The difference between these groups was not statistically significant in total ($p = 0.459$, Fig. 5) nor when sub-grouping into syringe systems ($p = 0.246$).

Movement of the needle in the soft tissue

With the 2-ml syringe, a deviation in the soft tissue of 2.93 mm (SD 1.74) with the 5-ml disposal syringe of 2.24 mm (SD 0.87) and with the thumb ring syringe of 2.28 mm (SD 1.06) was seen. The deviation of the active aspirating syringe was 2.1 mm (SD 0.75). Only the C-CLAD had a significant lower deviation compared to the four other syringes with a mean deviation of 0.93 mm (SD 0.71) (each $p < 0.001$; Fig. 5).

Discussion

Especially during IANB, aspiration is more than important as the inferior alveolar nerve is in a close relation to important arterial and venous vessels. Intravasal application, even in very small volumes, may produce toxic reactions including convulsions and apnea or even death also due to a reversal of carotid blood flow due to the high injection pressure [8]. The precise positioning of the needle is one of the most

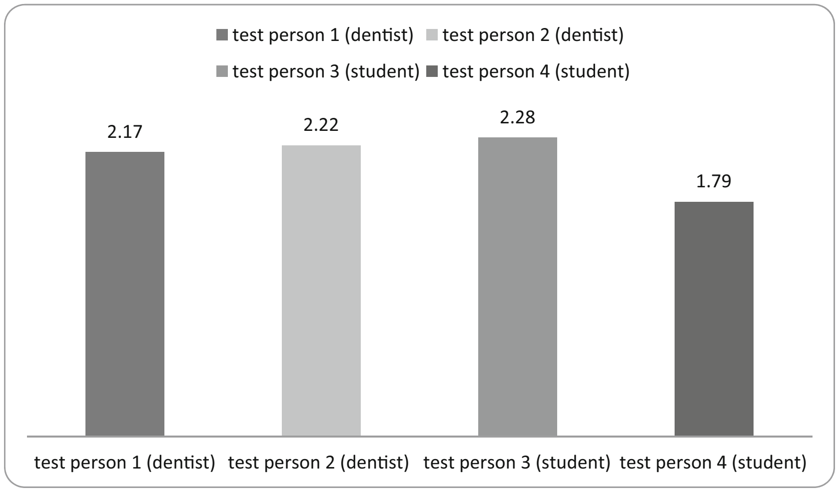

Fig. 5 Individual influence of the test persons referring to the movement in space (average values of all three axes; data in mm)

important factors for the success of IANB without causing any harm [13, 18–20]. Accordingly, the probability of a falsified result in the sense of a false-positive or a false-negative aspiration could be reduced by precise positioning of the needle. In this first video-monitored study, it could be shown that there is a system-dependent deviation of the syringes during double aspiration. This involuntary movement of the needle—that may not be detected by the eye—bears the risk of a dislocation, an intravasal injection as well as an injury of the soft tissue.

No significant differences in regard of the side of the mandible (left and right) were seen. This is in accordance to others [21, 22]. It is generally recommended that during administration of local anesthetics, the patient should be placed in a supine position. Though, no statistically significant differences were observed in the different angles of inclination (0°, 25°, and 45° backward). Also, there was no significant influence of the test persons' experience even if one less-experienced test person showed less deviation (not significant) during aspiration.

The results of system-dependent involuntary movements of different syringes are in accordance to the literature. In accordance, Delgado-Molina et al. as well as Lethinen and Aarnisalo found a correlation between the used syringe system and the number of positive aspirations [23, 24]. In the present study, the disposable syringe with a capacity of 2 ml has shown the largest deviation during the aspiration, with an average of 2.84 mm. The 5-ml disposable syringe showed the third largest deviation with 2.36 mm. One reason for this may be the ambidextrous use during aspiration [1]. The obvious difference, between the 2- and 5-ml disposable syringes, could be result of the different frictional forces between the plunger and syringe corpus. Those are higher with a 2-ml disposal syringe compared to those of the 5-ml disposal syringe**.** The thumb ring syringe has shown the second largest movement during aspiration. Eifinger et al. described the aspiration mechanism of syringes with a thumb ring as adverse**.** The authors reported that the disadvantage of this syringe system is that it must be actively moved by tractive force. This involves a divergence of needle and syringe tip within the tissue.

The passive syringe system showed the lowest level of dislocation when compared to the other manual syringe systems at examination. The reason for this could be found in the introduction of the aspiration, as the ring of the syringe is easy to reach and well placed on the syringe corpus During aspiration and injection, noencompassing is necessary. Only at the beginning of the aspiration, the release by the metal ring of the syringe may lead to an undesired movement, which is small compared to the other manual syringe systems.

The C-CLAD showed the significant lowest deviation in space and in tissue during aspiration compared to the other syringe systems. This can be explained by the ergonomical shape of the syringe grip which allows a tactile handling. But even more important is the fact that the implementation of the aspiration is not manual; it is started by a foot pedal and is ultimately performed at the base station of the system. The only task of the hand is to hold the syringe in the right position during the aspiration. Accordingly, the deviation source of error during aspiration could be minimized. Further investigations are necessary, if the clinical use of the C-CLAD leads in vivo to a lower rate of positive aspiration during IANB.

Conclusion

A movement during double aspiration is unavoidable. Creating the negative pressure in the cartridge by pressing seems to be better than by pulling (disposables, thumb ring). Activation of aspiration by foot pedal instead of hand improves the quality of the IANB. The deviation of the manual devices is two- to threefolds higher compared to a C-CLAD.

Compliance with ethical standards This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest PD Dr. Peer W. Kämmerer and Prof. Dr. Daubländer are giving lectures for 3M ESPE, Sanofi as well as for Septodont on the topic of local dental anesthesia. Both are involved in student teaching courses. P.W. Kämmerer declares that he has no conflict of interest. D. Schneider declares that he has no conflict of interest. A.A. Pacyna declares that he has no conflict of interest. M. Daubländer declares that she has no conflict of interest.

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Informed consent For this type of study, formal consent is not required.

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