Eur J Oral Sci 1995; 103: 388–393
Printed in Denmark . All rights reserved

EUROPEAN JOURNAL OF
ORAL SCIENCES
ISSN 0909-8836

Condensation pressure during amalgam placement in patients

Adrian Lussi, Matthias Brunner, Peter Portmann and Walter Bürgin
Department of Operative, Preventive and Pediatric Dentistry, University of Bern, School of Dental Medicine, Freiburgstrasse 7, CH – 3010 Bern, Switzerland

Lussi A, Brunner M, Portmann P, Bürgin W: Condensation pressure during amalgam placement in patients. Eur J Oral Sci 1995; 103: 388–393. © Munksgaard, 1995.

The purpose of this study was to investigate the condensation pressure during amalgam placement in patients. Forty-four practitioners were asked to fill two class 2 cavities in the lower jaw on their patients in their own practice with the aid of a force-measuring plugger. This device, with semiconductor strain gauges, allowed the dentist to have an identical tactile feedback as with any other plugger. Three different amalgams, with different shapes of alloy particles, were tested. The results showed a maximum condensation pressure of 8.9±2.4 MPa and 5.5±1.8 MPa with a small and a large amalgam plugger, respectively. Average condensation pressures were 3.7±1.3 MPa for the small and 2.2±0.9 MPa for the large instrument. The total working time required to fill a cavity was on average 131 s; the amalgam was effectively condensed for 44 s. No significant differences between amalgams with different shapes of alloy particles, no influence of time of day, and no difference between female and male dentists were found. This study showed that the condensation pressure is lower than often recommended, and that it is not statistically different from the values obtained in a previous laboratory study (1).

Key words: amalgam; condensation force

A. Lussi, Klinik für Zahnerhaltung, Freiburgstrasse 7, CH – 3010 Bern, Switzerland
Telefax +41-316329875. E-mail: buergin@zmk.unibe.ch

Accepted for publication June 1995

Amalgam is still the most often used restorative material for posterior teeth. The physical properties and therefore the longevity of amalgam restorations are among other factors determined by the dentist's handling behaviour, the trituration time, the mixing ratio of alloy and mercury, and the condensation pressure applied by the dentist (2-6). The duration of the trituration and the mixing ratio may be controlled accurately, but the condensation pressure differs among individuals and is difficult to control.

Recommended optimum condensation pressures were mainly derived from laboratory investigations and are between 10–20 MPa (=1–2 kp/mm^2) (7–9). It has been shown that amalgam condensation under or close to *in vivo* conditions revealed condensation pressures significantly below those mentioned above (1, 10–12). In an earlier study, maximum condensation pressures ranged between 4.1 MPa (diameter of the plugger 1.8 mm) and 9.2 MPa (diameter of the plugger 1.15 mm) (1). To our knowledge, there are no data available of condensation pressures applied by more than a few dental practitioners in their own (extramural) practice. The aim of this study was therefore to build a miniaturized force-measuring device in order to use it under actual clinical conditions and to investigate the condensation patterns when using different types of amalgams (Dispersalloy, ANA 2000, Valiant).

Materials and methods

Based on the experience with the previous instrument (1), a modified force-measuring instrument was built using semiconductor strain gauges. The new instrument was identical to the commercially available instrument in terms of grip (finger placement) and rigidity (force feedback). The surface areas of the modified amalgam pluggers used were 1.09 mm^2 and 2.72 mm^2, respectively.

The measuring device was built according to the following procedure: a commercially available amalgam plugger (Deppeler, Rolle, Switzerland) with a flat condensing surface was used. By finite element methods, a wire model was built of the tip

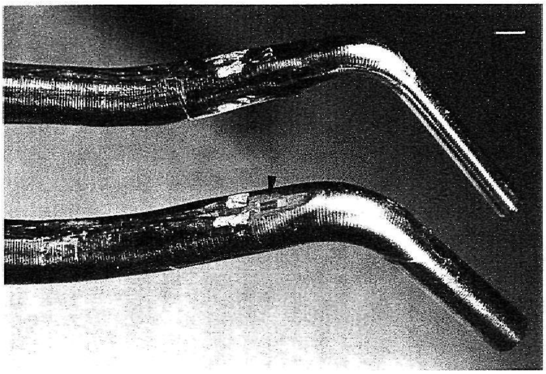

Fig. 1. The pluggers used with the strain gauges in position (arrow: upper strain gauge of the large plugger, bar=1 mm).

and the shaft in order to allow an optimal placement of the semiconductor strain gauges. Care was taken to optimize the location of the sensors in order to minimize the sensitivity to forces perpendicular to the long axes of the plugger and to temperature (Fig. 1).

The semiconductor strain gauges are so sensitive to strain, that a minimal distortion of the underlying metal already gives a reasonable signal. Much care was taken to fit the sensors properly to the shaft surface, which was prepared in the following way: first the circumference was slightly flattened with a small milling cutter on the top and bottom. Then the four copper wires connecting the two strain gauges (half bridge) to the electrical instrument were attached to the upper and lower side of the shaft using a commercially available cyanoacrylate adhesive (M Bond 200; Micro Measurement Company, Romulus, MI, USA) and cut to the correct length in order to allow the connection to the thin gold wires from the strain gauges. Then the surface was cleaned chemically (M-Prep Conditioner A and B; Micro Measurement Company) and the strain gauges (ESU-025-500; Entran International, Fairfield, CT, USA) were glued to the instrument using M-Bond 600 two-component adhesive. A considerable pressure had to be used in order to generate a very thin layer of glue, which also served as insulator. These and the later steps were all done using a microscope with 20× magnification. The adhesive was hardened afterwards for 24 h at 100°C. Then the very fine (38 μm) gold wires from the strain gauges were connected to the copper wires using a conducting glue (Elecolit 340; 3M, Rüschlikon, Switzerland). These procedures were carried out on both sides of the instrument in order to obtain a half-bridge design. Finally, the strain gauges and the wires were covered with several layers of a transparent flexible varnish (PU 100; Schenk, Nänikon, Switzerland), such that the whole instrument was waterproof and impact protected (Fig. 1). The electrical part of the force device was basically the same as described by Lussi & Bürgin (1), with the addition that this time not only was the force signal integrated, but also the duration of force application (effective condensation time), thus allowing an easy calculation of the average condensation force/pressure (Fig. 2). In addition, the low pass filter in the instrumentation amplifier was set to allow frequencies of the force signal up to 50 Hz. The signals were recorded on a fast three-channel recorder (Rikadenki R-03). From these charts, the following parameters were calculated for each dentist:

1) The maximum condensation force (N), calculated as the mean of the ten highest peaks of the force signal on the chart.

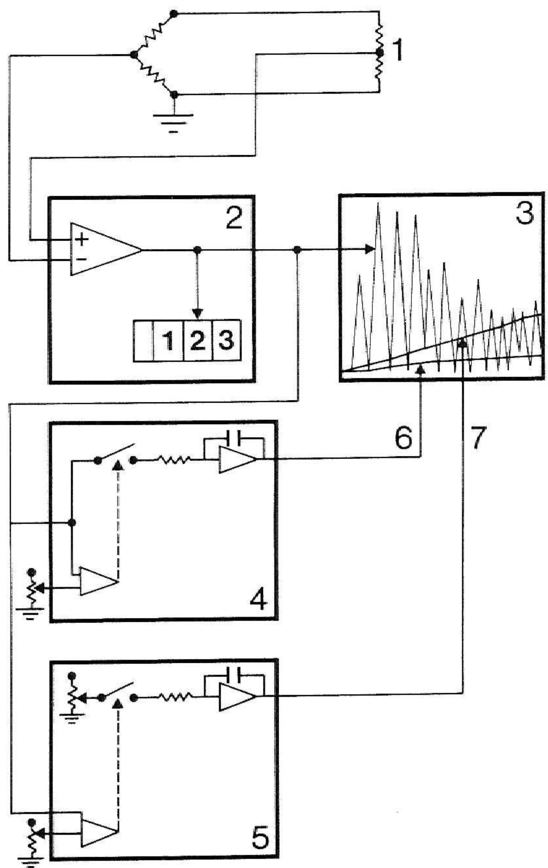

Fig. 2. Electronic circuit diagram of the experimental set-up (1) strain gauge, (2) amplifier, (3) recorder, (4) force integrator, (5) time integrator, (6) integrated force, (7) effective condensation time.

2) The average condensation force (N), calculated from the integral of the force over time divided by the recorded effective condensation time.
3) The maximum and average condensation pressure (MPa), calculated from the above forces divided by the plugger surface area of the corresponding instrument.
4) Total time to condense the filling.

All participating practitioners (8 female, 36 male) had attended a refresher course 3 to 5 yr previously, where they filled a cavity preparation with amalgam in a mannequin head. They were visited at their own office by the person conducting the trial and asked to schedule at least one of their own patients in their office for a class 2 restoration in the lower jaw. Each restoration was condensed, starting with the small and then using the large plugger. Table 1 gives an overview of the precapsulated amalgam used. From each type of amalgam the same batch was used for all fillings. One of the recordings was made in the morning and the other in the afternoon in order to evaluate a possible difference. In total, 86 amalgam restorations (49 Dispersalloy [25 in the morning], 18 ANA 2000 [9 in the morning], 19 Valiant [10 in the morning]) were assessed. Preceding each recording, a careful calibration of the instrument was made with different forces, and after the trial a safety calibration was recorded. The instrument showed no deterioration during the whole 6-month period of the trial. However, the cabling system had to be repaired twice, because of interaction with sharp edges.

First, all data were analyzed by descriptive methods using the QQ- and box plot (Systat 5.0; Systat, Evanston, IL, USA). Further, an analysis of variance and the Tukey test for multiple comparisons were used. $P < 0.05$ was considered statistically significant.

Results

Condensation pressures employed with two amalgam pluggers for three types of amalgams are shown in Fig. 3. Maximum condensation pressure ranged between 8.1±2.1 MPa (Valiant) and 9.6±3.0 MPa (ANA 2000) for the small instrument, and 4.9±1.3 MPa (Valiant) and 5.9±2.0 MPa (Dispersalloy) for the large instrument. The corresponding numbers for the average condensation pressure were between 3.3±1.0 MPa (Valiant) and 4.1±1.2 MPa (ANA 2000) using the small, and 1.7±0.6 MPa (Valiant) and 2.4±1.0 MPa (Dispersalloy) for the large instrument. No statistically significant differences between the types of amalgam could be established. Overall, the results showed a maximum condensation pressure of 8.9±2.4 MPa and 5.5±1.8 MPa with a small (area=1.09 mm^2) and a large (area=2.72 mm^2) amalgam plugger, respectively ($P < 0.001$). Average condensation pressures were 3.7±1.3 MPa for the small and 2.2±0.9 MPa for the large instrument ($P < 0.001$).

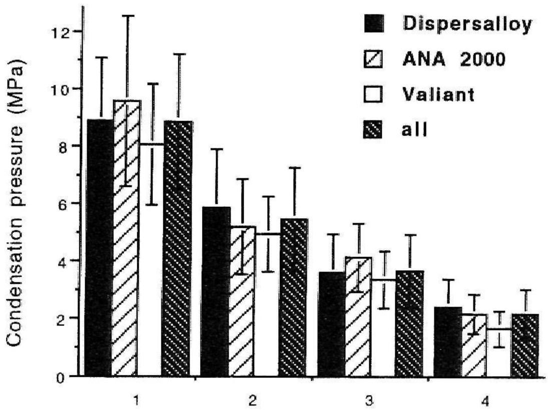

Fig. 3. Maximum condensation pressure (±SD) for the small (1) and the large plugger (2), and average condensation pressures for the small (3) and the large (4) plugger. No significant differences were found within groups.

Total working time to condense amalgam with the small plugger was on the average 62.5±26.7 s and with the large plugger 68.8±41.6 s yielding a total working time to fill the cavity of 131.3 s (Fig. 4).

The effective condensation time (e.g. the time during which force was applied) was 21.3±7.9 s for the small and 22.2±11.8 s for the large condensation instrument, resulting in a total effective condensation time of 43.5 s. This means that a total

Table 1

Composition of particles by weight-percent, alloy-mercury and types of alloys investigated

Metal	Ag %	Sn %	Cu %	Zn %	Other	Alloy/Hg	Type of alloy
ANA 2000	43	29.6	25.4		2% Hg	1:1	lathe-cut particles of identical composition
Dispersalloy	69.3	17.9	11.8	1		1:1	lathe-cut particles plus spherical eutectic Ag/Cu particles
Valiant	49.5	30	20		0.5% Pd	1:0.76	spherical particles of identical composition

of 87.8 s were pauses in the condensation process. Again, there were no statistically significant differences between the different amalgams under study (Fig. 4).

No statistically significant differences were found when analysing condensation pressures for male and female dentists. On average, the tendency was for female dentists to use less condensation pressure and less working and condensation time to fill a cavity.

Fig. 5 gives an overview of condensations pressures, of fillings made either in the morning (9–11 a.m.) or in the afternoon (2–4 p.m.). There was a tendency for lower condensation pressures in the afternoon, although no significant differences were found.

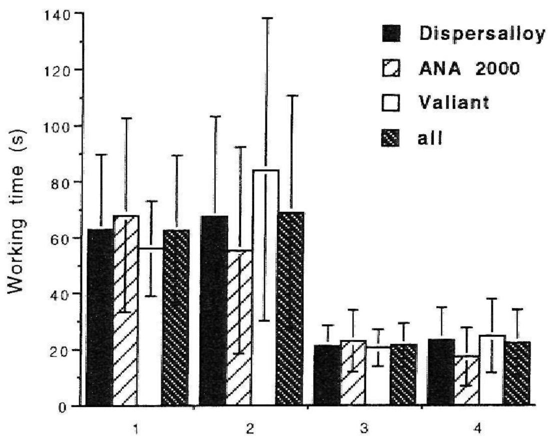

Fig. 4. Total working time (±SD) for condensation with the small (1) and the large (2) plugger, and the effective condensation time using the small (3) and the large (4) plugger. No significant differences were found within groups.

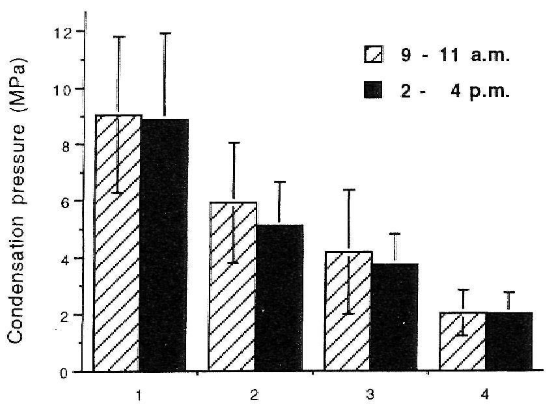

Fig. 5. Dependence of time of day: maximum condensation pressure (±SD) for the small (1) and the large plugger (2), and average condensation pressures for the small (3) and the large plugger (4) in the morning and in the afternoon. No significant differences were found within groups.

Discussion

This study showed that under normal clinical practice conditions the maximum condensation pressures employed were considerally lower than those recommended by Standard Institutions or by other authors (8, 9). On average, maximum condensation pressures were 8.9±2.4 MPa for the small and 5.5±1.8 MPa for the large condensation instruments. In this context, it is interesting to note that force values were smaller using the small plugger (9.65 N) compared to the large instrument (14.88 N). These values are in the range reported in other *in vitro* or *in vivo* investigations (1, 10–12). This difference could be due to the fact that dentists started to condense amalgam carefully with the small plugger and then, for reasons of practical convenience, switched to the large instrument applying their individual maximum force. Using the larger instrument would also decrease the penetration into the condensed amalgam and, consequently, increase the force applied by the dentist (11).

Taking the force values achieved during condensation of amalgam, the surface areas would have to be reduced to 0.64 mm^2(9.65 N/ 15 MPa, small plugger) and to 0.99 mm^2 (14.88 N/ 15 MPa, large plugger) to achieve the above-mentioned pressure of 15 MPa. This would lead to a diameter of 0.91 mm for the small and of 1.12 mm for the large condensation instrument. However, such small instruments are not practical to condense an amalgam filling. Further such small instruments would penetrate rather than condense the amalgam. MAYER (9) used a plugger with a diameter of 2.5 mm and recommended a condensation pressure of up to 10 MPa. As shown in the present study, this would lead to forces which are not applied by dental practitioners in their own practice.

Maximum condensation pressure was smallest for Valiant containing spherical particles (Fig. 3), although the differences with the other amalgams tested were not significant.

Other investigators also found smaller condensation pressures using amalgam with spherical particles compared to the amalgam containing lathe-cut particles. It seems that the condensation force using lathe-cut-containing amalgams is limited by the strength of the operator, whereas with spherical particle alloys, the condensation force is governed by the nature of the material (12, 13).

Many studies showed that physical properties such as compressive strength, porosity, and residual mercury content are affected by significantly reducing the condensation pressure below 15 MPa

(3, 14–16). On the other hand, it has been shown in laboratory investigations that high-copper spherical particle alloys are not as sensitive to decreased condensation pressure as are other alloys (3, 17), and therefore a larger condenser could be used. However, it has also been shown that the clinical performance (marginal integrity and fracture) of amalgams containing only spherical particles is inferior compared to amalgams containing lathe-cut particles (18, 19).

The indication of maximum condensation force only, however, may not be sufficient. The force recordings showed that some of the dentists produced peaks of very short duration where others applied the force a longer time. The average condensation pressure is able to take into acount the different condensation patterns and might therefore be a more reliable parameter to measure. Both parameters were easily accessible with the measuring device described. It allowed the dentists to condense amalgam in the mouths of the patients without any special procedures. This was possible by the use of miniaturized strain gauges, which were glued in positions where they did not hinder the operator. The instrument used in this investigation had the advantage of not changing the normal grip of the plugger, thus guaranteeing an optimal tactile feedback. Condensation forces applied while filling a cavity in the mannequin head in the same jaw were not significantly different from the forces used *in vivo* by the same dentists (results not shown). This could be due to a certain learning effect, as all participating dentists were informed about the 'low' condensation pressures they had applied a few years earlier, when they attended a post-graduate refresher course.

In order to test the influence of working performance during the day, the dentists were also asked to fill a cavity in the lower jaw in the morning (9–11 a.m.) and another in the afternoon (2–4 p.m.). It has been shown that the working performance is highest between 9 and 11 a.m. and lowest between 2 – 4 p.m. (20). It seemed that these periods had only a minor influence on maximum and average condensation pressures. Because the size of the cavity preparations in this *in vivo* study was not standardized, nor quantified, comparisons of condensations times e.g. morning/afternoon, male/female were not possible. No significant differences between the types of amalgam (Dispersalloy, ANA 2000, Valiant) could be established. It seemed that these parameters (condensation pressures) are inherent to the dentist and independent of the shape of the alloy particles used. The same was true with the condensation time. This is in contrast to other studies, where a significantly smaller condensation pressure was found for spherical alloys (12, 13). This difference could be due to the fact that the amalgams tested had a different alloy/mercury ratio, a different plasticity, and a different setting rate (10) which influenced the condensation force. Further, in the above mentioned studies each operator used different alloys, whereas in our study each dental practioner used only one type of amalgam. It was not mentioned in those studies how each operator was acquainted with the different alloys, which could have affected the condensation behaviour.

In summary, this study showed that the measuring device described allows recording of the dynamic aspects of the condensation of amalgam in a clinical setting without hindering the dentist in his/her work. From the results, it would also appear that the usual requirements of maximum condensation pressures are probably unrealistically high.

References

1. Lussi A, Bürgin WB. A new method to measure the condensation pressure of amalgam under *in vivo* conditions. *J Dent Res* 1987; **66:** 737–739.
2. Jørgensen KD, Esbensen AL, Borring-Möller G. The effect of porosity and mercury content upon the strength of silver amalgam. *Acta Odontol Scand* 1966; **24:** 535–553.
3. Clark AE, Farah JW, Clark TD, Etts C, Hamdi M. The influence of condensing pressure on the strength of three dental amalgams. *Operative Dent* 1981; **6:** 6–10.
4. Leitao J. Polishability of dental amalgam as influenced by condensation pressure and primary mercury content *Acta Odontol Scand* 1983; **41:** 327–331.
5. Iglesias AM, Sorensen SE, Carter JM, Wilko RA. Some properties of high-copper amalgam alloys comparing hand and mechanical trituration. *J Prosth Dent* 1984; **52:** 194–198.
6. Letzel H, van't Hof MA, Vrijhoef MMA. The influence of the condensation instrument on the clinical behavoir of amalgam restorations. *J Oral Rehabil* 1987; **14:** 133–138.
7. Rebel H. Konservierende Zahnheilkunde. München: Carl Hanser Verlag 1950; 139–140.
8. Jørgensen KD. Amalgame in der Zahnheilkunde. München, Wien: Carl Hanser Verlag, 1977.
9. Mayer R. Amalgam-Kondensation – maschinell oder manuell? *Dtsch Zahnärztl Z* 1984; **39:** 736–740.
10. Mahler DB, Mitchem JC. Effect of precondensation mercury content on the physical properties of amalgam. *J Am Dent Ass* 1965; **71:** 593–600.
11. Basker RM, Wilson HJ. Condensation of amalgam. The clinical measurement of forces and rates of packing. *Br Dent J* 1968; **124:** 451–455.
12. Brown IH, Maiolo C, Miller DR. Variation in condensation pressure during clinical packing of amalgam restorations. *Am J Dent* 1993; **6:** 255–259.
13. Basker RM, Wilson HJ. Spherical particle amalgam. *Br Dent J* 1971; **130:** 338–342.
14. Hegdahl T, Silness J. Porosity of spherical amalgam. *Scand J Dent Res* 1970; **78:** 62–68.
15. Ekstrand J, Jørgensen R, Holland RI. Influence of variations in preparation of dental amalgam on dimensional stability and porosities. *J Prosth Dent* 1985; **54:** 349–355.

16. EDEN GT, WATERSTRAT RM. Effect of packing pressures on the properties of spherical alloy amalgams. *J Am Dent Assoc* 1967; **74:** 1024–1029).
17. BROWN IH, MILLER DR. Alloy particle shape and sensitivity of high-copper amalgams to manipulative variables. *Am J Dent* 1993; **6:** 248–254.
18. LEIDAL TI, DAHL JE. Marginal integrity of amalgam restorations. *Acta Odontol Scand* 1980; **38:** 81–88.
19. OSBORNE WJ. Three year clinical performance of eight amalgam alloys. *Am J Dent* 1990; **3:** 157–159.
20. LEHMANN G. Das physiologische Leistungsvermögen des Menschen. In: Arbeitsmedizin I, München: Carl Hanser Verlag 1965; 349–361.