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Analysis of shrinkage of different gutta-percha types using optical measurement methods

Summary

The aim of this study was to compare the shrinkage of alpha- and beta-gutta-percha of the Multifill-system with commercial gutta-percha. Ten gutta-percha blocks of each of the three types were used. Speckle pattern shearing interferometry was used to prove that no trapped air and material defects were present in the specimens. The optical triangulation method was applied to assess shrinkage. The three gutta-percha types were examined after heating up to 90 °C and cooling down to 35 °C. Commercial gutta-percha showed less shrinkage (6.5%) than alpha- (7.2%) and beta-gutta-percha (7.3%; p = 0.0051 for both comparisons; Wilcoxon's signed rank test). There was a significant difference between alpha- and beta-gutta-percha (p = 0.0093; Wilcoxon's signed rank test). In the range of 45 °C to 40 °C, alpha- and beta-gutta-percha revealed the highest shrinkage (2.2%/5 °C and 2.1%/5 °C, respectively). Commercial gutta-percha showed the highest shrinkage (1.1%/5 °C) in the range of 55 °C to 40 °C. Overall, shrinkage of all types of gutta-percha was higher than could be assumed from former studies.

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Introduction

The thermoplastic property of gutta-percha is used to obturate the root canal system in three dimensions. The gutta-percha is heated and placed into the canal as an amorphous melt, where it cools down to body temperature and stiffens. During this cooling process, the gutta-percha shrinks. Thereby voids and volume loss may occur within the filling.

Since the introduction of the warm vertical compaction technique of Schilder (1967), several obturation techniques using thermoplasticized gutta-percha have been developed and many different types of gutta-percha are available as root canal filling

Tab. I Chemical composition of different gutta-percha types.

	ROEKO gutta-percha (Marchiano & Michailesco 1989)	Average trademark (Friedman et al. 1977)
Gutta-percha	22%	20%
Barium sulfate	3%	11%
Zinc oxide	75%	66%
Contrast medium	not applicable	3%

material. The composition and the physical properties vary between the different brands (Tab. I). Increasing the amount of gutta-percha seems to cause a higher brittleness, while zinc oxide influences the inherent plasticity. Heating dental gutta-percha up to 130 °C causes physical changes, unlike chemically pure gutta-percha. Additives in dental gutta-percha cause the altered material behaviour (Combe et al. 2001).
In recent years, new gutta-percha has been formulated which contains the alpha-form of trans-polyisoprene. The Multifill-system (Loser & Co GmbH, Leverkusen, Germany) makes use of warm gutta-percha containing alpha- (Phase II) and beta-gutta-percha (Phase I) which envelops an Ni-Ti core. The gutta-percha is heated in a special heating oven. The compactor, which looks like an inverted Hedström file, is first covered with a layer of Phase I (beta-gutta-percha) and then with a layer of Phase II (alpha-gutta-percha). By varying the speed at which the compactor is pulled out of the gutta-percha, the thickness of the layers of the respective gutta-percha types can be influenced. After the compactor is inserted into the canal, it is "unscrewed" from the material to leave behind a root canal filled with pure gutta-percha. The manufacturer states that minor shrinkage during cooling down is an advantage of alpha-form gutta-percha over beta-gutta-percha. It becomes sticky while softening and adheres to dentine. It is known that conventional gutta-percha exists in the beta-form of trans-polyisoprene (Cohen 1984). The beta-gutta-percha used in Phase I of the Multifill-system is very similar to commercial gutta-percha, but the exact composition is the manufacturer's secret. It shows a high viscosity and does not adhere to dentine (Cohen et al. 1992). The manufacturer claims that a homogeneous, void free filling of all ramifications and lateral canals is possible with pure gutta-percha without the use of sealer.
Niss et al. (1996) showed that the thermoplastic gutta-percha method ("Multi-Phase-II" method, the predecessor system of Multifill, McSpadden 1997) achieved high apical sealing ability even without sealer. Gilhooly et al. (2000) showed that canals filled by Multi-Phase gutta-percha obturation and sealer had significantly less apical dye leakage than those obturated by lateral compaction.
Two non-destructive, contact-free measurement methods were used in the present paper. Speckle pattern shearing interferometry (SPSI) was used to assess sample homogeneity and sample deformations. SPSI is a coherent optical method which was developed in 1973 and has become popular as a tool for whole-field non-destructive testing (Hung & Taylor 1973, Leendertz & Butters 1973). With the technique of SPSI, strains and other displacement derivatives of an object surface can be visualized with the use of laser light. Using this method the homogeneity of materials can be assessed. The idea behind this use of SPSI is that a defect inside the material causes surface deformations while loading the samples. Trapped air, for example, will expand while heating and cause a change in the surface of the sample. SPSI is able to measure these changes in the submicron range. The presence of surrounding air does not affect the measurements because SPSI does not measure the deformation itself but its first derivative.
The optical triangulation method is also a non-destructive and contact-free testing method (Fig. 1). It can be used to analyze the shrinkage of materials during the cooling process.
The aim of the present study was to compare the shrinkage behaviour of commercial gutta-percha with that of Multifill-system alpha- and beta-gutta-percha using the optical triangulation method after scanning the specimens using SPSI. We see this as an approach to investigate the risks of void formation and volume loss of root canal filling materials.

Materials and Methods

Alpha- and beta-gutta-percha sticks of the Multifill-system and commercial gutta-percha plates (ROEKO, Langenau, Germany) were used. The samples were stored at room temperature before usage.
Gutta-percha was heated in an aluminium cylinder which was fixed on an insulating plate together with an aluminium clamp for the temperature sensor (Fig. 2). The coefficient of thermal expansion of aluminium is 23.1×10^{-6}/Kelvin, the expansion of the aluminium cylinder with a diameter of 30 mm and a depth of 3 mm is 0.13% in the temperature range between 35 °C and 90 °C. The cylinder was coupled with a thermostat (Model E5CS-X, OMRON Corporation, Japan) to adjust the temperature exactly while being controlled with the temperature sensor. For each of the three gutta-percha types, ten specimens in the form of blocks were used.
SPSI was used to ensure that there were no voids in the specimens.

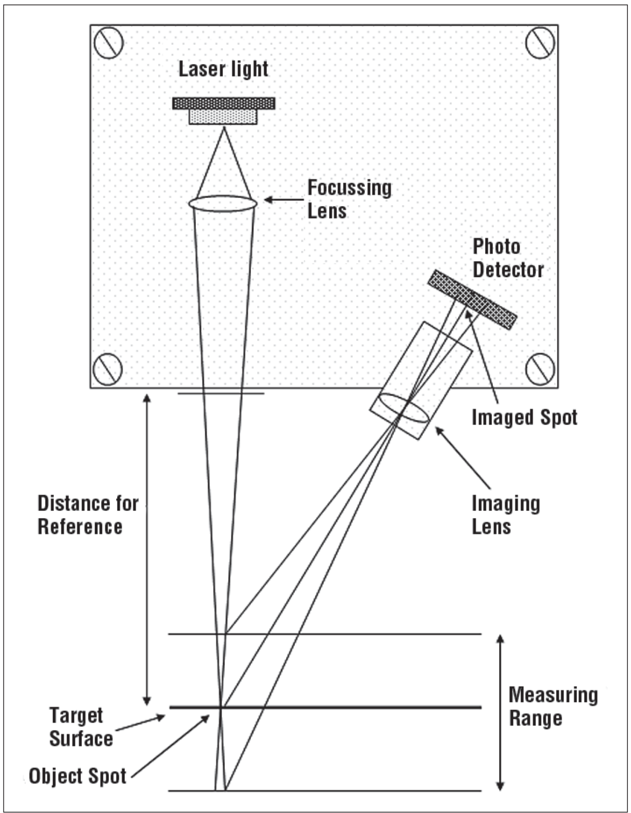

Fig. 1 Diagram of the triangulation method.

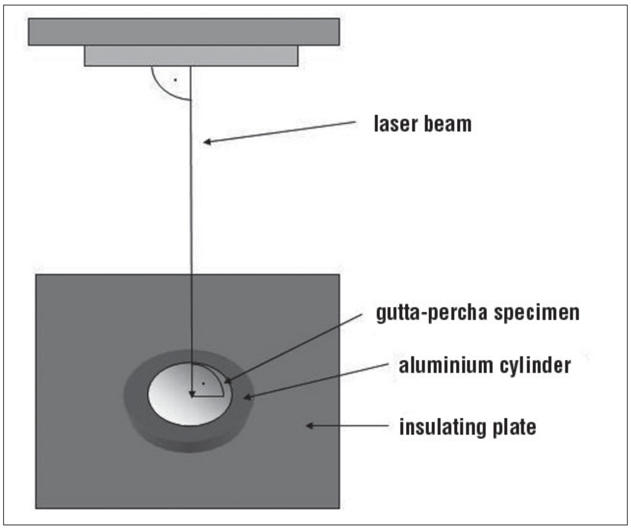

Fig. 2 Drawing of the experimental setup measuring the gutta-percha specimen.

The optical triangulation method was used to analyze the shrinkage of the specimens during the cooling process. The M5 distance sensor was used (Mikroelektronik GmbH, Eching, Germany). A laser beam source (wavelength 900 nm) illuminates and interacts with the sample surface. The beam is reflected or scattered to the sensor, which gathers the light. To calibrate the device, a video camera measures the light which is reflected from the object and recorded as a reference. An optical system images the surface onto a spatially resolving detector (Fig. 1). The sampling frequency of the system is 2.5 kHz and the available measurement range is 10 mm.
The tests were started at a temperature of 90 °C. In order to measure the thickness of the specimens, the aluminium cylinder was positioned in such a way that the surface of the gutta-percha specimen was parallel to the measuring table to assure constant thickness of specimens. The laser was positioned perpendicularly to the surface of the specimen (Fig. 1 & 2). The detector contained a sensor which controlled the intensity of the reflection of the gutta-percha specimens. This was necessary because the intensity of the reflection decreased at high temperatures, probably due to changes in the molecular structure of the specimens. The sensor constantly measured the reflection and adjusted the intensity of the laser light in order to get a constant reflection intensity even at high temperatures (Fig. 1).
After heating the specimens to a temperature of 90 °C, the distance sensor was standardized to zero and adjusted to the middle of the specimens. Then the specimens were cooled down to 85 °C and the temperature was maintained long enough to measure the established distance. This procedure was repeated at each step (5 °C each), until a temperature of 35 °C was reached. The specimens were kept at 35 °C for an hour and a half to allow the complete phase displacement of the polyisoprene chains. It was not possible to measure the absolute thickness of the specimens at the beginning of the measurement series (90 °C). Therefore, the relative changes in thickness were recorded while cooling down the specimens. At the end of the series (35 °C), the absolute thickness was measured. For this purpose, the point of the laser beam on the gutta-percha specimens at 35 °C was marked. Then the thickness was measured at this point with a calliper.
The statistical analysis for each sample was performed by calculating the shrinkage in percent. The measured thickness at 35 °C was subtracted from the value calculated for 90 °C. The difference obtained was expressed as a percentage of the value at 90 °C. Statistical evaluation was performed by means of the Kruskal-Wallis test and Wilcoxon's signed rank test.

Results

SPSI showed that no trapped air was evident in all thirty specimens. No specimen was discarded due to voids and material defects.
Table II shows the thickness of the three gutta-percha types at each measured temperature between 90 °C and 35 °C. Commercial gutta-percha showed less shrinkage (6.5%) than alpha- (7.2%) and beta-gutta-percha (7.3%; $p = 0.0051$ for both comparisons). There was a significant difference between alpha- and beta-gutta-percha ($p = 0.0093$).
In the range between 90 °C and 45 °C, the shrinkage of alpha- and beta-gutta-percha was almost linear with 0.5%/5 °C to 0.7%/5 °C (Fig. 3). Between 45 and 40 °C, alpha- and beta-gutta-percha revealed the highest shrinkage (2.2% and 2.1%/5 °C, respectively). In the range of 40 to 35 °C shrinkage was less dis-

Tab. II Means and standard deviations (SD) and lower (LCL) and upper (UCL) 95% confidence limit of the thickness of the specimens in relation to the temperature.

	alpha-gutta-percha (n = 10)				beta-gutta-percha (n = 10)				ROEKO gutta-percha (n = 10)			
Temp.	Mean	SD	LCL	UCL	Mean	SD	LCL	UCL	Mean	SD	LCL	UCL
90 °C	3.32	0.14	3.23	3.40	3.22	0.12	3.14	3.29	3.20	0.12	3.21	3.20
85 °C	3.30	0.14	3.22	3.38	3.20	0.12	3.13	3.27	3.19	0.12	3.20	3.19
80 °C	3.28	0.14	3.20	3.36	3.18	0.12	3.11	3.25	3.17	0.12	3.18	3.17
75 °C	3.26	0.14	3.18	3.34	3.16	0.12	3.09	3.23	3.15	0.12	3.17	3.15
70 °C	3.24	0.14	3.16	3.32	3.14	0.12	3.07	3.21	3.14	0.12	3.15	3.14
65 °C	3.22	0.14	3.14	3.31	3.12	0.12	3.05	3.19	3.12	0.12	3.13	3.12
60 °C	3.21	0.14	3.13	3.29	3.11	0.12	3.04	3.17	3.11	0.12	3.12	3.11
55 °C	3.19	0.14	3.11	3.27	3.10	0.12	3.02	3.16	3.10	0.11	3.10	3.10
50 °C	3.18	0.14	3.09	3.26	3.07	0.12	3.01	3.14	3.07	0.11	3.08	3.07
45 °C	3.16	0.14	3.08	3.24	3.06	0.11	2.99	3.12	3.04	0.11	3.05	3.04
40 °C	3.09	0.13	3.02	3.17	2.99	0.11	2.93	3.06	3.00	0.11	3.01	3.00
35 °C	3.08	0.13	3.00	3.16	2.98	0.11	2.91	3.05	2.99	0.11	3.00	2.99
Shrinkage (%)	7.18	0.09	7.12	7.24	7.31	0.10	7.25	7.37	6.51	0.05	6.51	6.51

Shrinkage is given in percentages of the thickness of the respective specimen at 90 °C.

tinct with 0.5%/5 °C (alpha-gutta-percha) and 0.4%/5 °C (beta-gutta-percha).
In the range of 90 to 60 °C, ROEKO gutta-percha showed an almost linear shrinkage of 0.4%/5 °C to 0.6%/5 °C. Between 60 to 55 °C, the shrinkage was less pronounced with 0.2%/5 °C. ROEKO gutta-percha showed the highest shrinkage (1.1%/5 °C) in the range of 55 to 40 °C. Between 40 and 35 °C, however, the shrinkage was slightly weaker with 0.5%/5 °C (Fig. 3).

Discussion

The shrinkage behaviour of gutta-percha after obturation is important for its use as an endodontic filling material. It is supposed that shrinkage of gutta-percha inside the root canal can cause voids and gaps between the gutta-percha and the canal wall.
Coronal leakage is one of the main problems for endodontic failure. It can be caused by bacterial penetration of the root canal after obturation. Gutta-percha and sealer alone are known to be an insufficient barrier for bacterial penetration in coronally unsealed obturated root canals (Gish et al. 1994). Khayat et al. (1993) also investigated teeth filled with gutta-percha. Without sealer, they found complete bacterial penetration within two days. With sealer, bacterial penetration occurred within less than 30 days.
The manufacturer of the Multifill-system claims that the use of sealer is not necessary when using Multifill gutta-percha. The gutta-percha of the Multifill-system is heated in a special heating oven up to 81 to 82 °C.
In the present study the maximum temperature was set at 90 °C because different commercially available ovens show a heating temperature of the gutta-percha up to 93 °C (Malagnino et al. 1997). To resemble body temperature, 35 °C was chosen as the lowest temperature. The specimens were kept at 35 °C for an hour and a half to allow the complete phase displacement of the polyisoprene chains. At this temperature, the gutta-percha is solid and does not show further changes in molecular-phase transformation of long chain polymer materials (Schilder et al. 1985). The expansion of the aluminium barrel in the range of 35 °C to 90 °C is 0.13%. Therefore, the influence of the expansion of the aluminium barrel on the outcome of the tests is negligible, when compared with the shrinkage of the gutta-percha specimens with 6.5%, 7.2% and 7.3%, respectively.

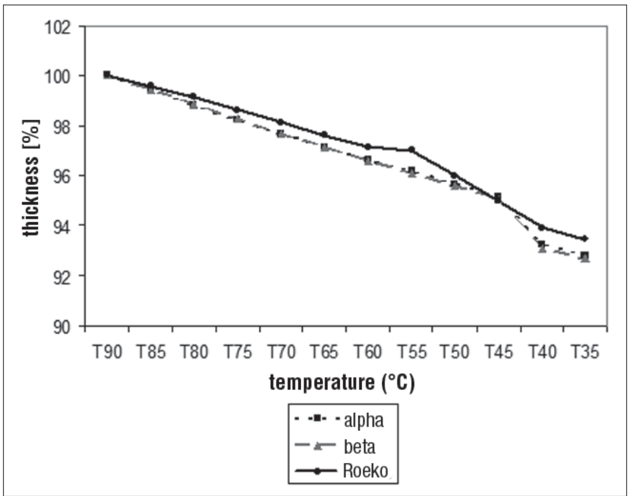

Fig. 3 The decrease in temperature induced shrinkage in the three gutta-percha specimens. Thickness is given in % of the thickness of the respective specimen at 90 °C.

Optical systems like SPSI or optical triangulation seem to be adequate methods to precisely examine the dental materials, because they measure directly and non-destructively (Hung & Taylor 1973, Leendertz & Butters 1973). Regardless of the material, SPSI is able to measure the structure of an object in a contact-free way, with sensitivity in the submicron range and without being influenced by the surrounding environment (Steinchen et al. 1997, Steinchen et al. 1998). Thus, the pre-selection of specimens excluding voids or locked air may be more reliable than in former studies.
The triangulation method was used to measure the shrinkage of the gutta-percha specimens. Considering the standard deviations and confidence limits in the present study, it seems to be a precise measuring technique that can be used for many purposes. Up to now, there is no other published study where this method is used with regard to endodontology.
The results show that ROEKO gutta-percha showed less shrinkage (6.5%) than alpha- (7.2%) and beta-gutta-percha (7.3%) in the 90 to 35 °C range. In accordance with the statement of the manufacturer, alpha-gutta-percha indeed showed less shrinkage than beta-gutta-percha. However, both Multifill gutta-percha types showed more shrinkage than commercial gutta-percha. Since the manufacturer justifies the recommendation of omitting the sealer by stating that alpha-gutta-percha shows lower shrinkage compared to beta-gutta-percha our conclusion is that this recommendation cannot be supported. Sealer has to be used when filling the root canal with Multifill gutta-percha. Today, there is no question of using sealer and studies show that sealer must be used for sufficient root-canal filling. Khayat et al. (1993) found less bacterial penetration using gutta-percha in combination with sealer compared to a group using gutta-percha only. Du Lac et al. (1999) compared the obturation of lateral canals by using six techniques with and without sealer. Vertical condensation, carrier-based thermoplasticized gutta-percha, continuous wave condensation and vertically condensed high-temperature gutta-percha were able to fill the lateral canals significantly better when sealer was used. In contrast, Niss et al. (1996) achieved high apical sealing ability even without sealer. However, this study used the dye penetration method, which is questionable (Wu & Wesselink 1993, Oliver & Abbott 2001). Furthermore, no vacuum was used in their study, so air bubbles may have inhibited the penetration of the 2% methylen blue.
To compare the results of the present study with other studies that use a temperature range between 80 °C and 35 °C, the percentage of observed shrinkage was calculated for this temperature range. In the range between 80 °C and 35 °C, the present study observed shrinkage of 6.1%, 6.3% and 5.7% for alpha-gutta-percha, beta-gutta-percha and ROEKO gutta-percha, respectively. In contrast to these findings, Schilder et al. (1985) reported shrinkage of different dental gutta-percha samples varying between 3.8% and 5.3% for temperatures between 80 °C and 37 °C. Measurements were taken using dilatometric analysis. Lee et al. (1997) used a modified volume dilatometry technique consisting of capillary tubes and a specimen chamber to determine shrinkage of four commercial gutta-percha types (Regular Flow Plugs, Easy Flow Plugs, Ultrafil, Thermafil). Ultrafil plugs showed the smallest shrinkage during the cooling process from 80 to 37 °C (2.2%), whereas Thermafil showed the greatest shrinkage (3.5%). The authors concluded that the extent of shrinkage depends on the exact chemical composition of the dental gutta-percha, which is in agreement with the results of Combe et al. (2001). Ultrafil gutta-percha (blue and white material) was compared with gutta-percha points using a differential

scanning calorimeter and a magnetic bearing torsional creep apparatus (GRASSI et al. 1989). Temperatures ranged from 70°C to 37°C. The blue material and the gutta-percha points had a shrinkage of 2.6%, the white material of 2.2%. Raw gutta-percha (100% polymer) showed the greatest shrinkage (4.6%). In comparison to these studies, the present investigation showed a higher shrinkage. This might be caused by the exact measuring technique.

Using thermoplastic filling methods, the gutta-percha is placed into the root canal at a high temperature (DONLEY et al. 1991). The main shrinkage occurs in the root canal. Methods for compensation of shrinkage are needed. The Thermafil system tries to compensate for this loss of volume by using a plastic carrier, which is placed in the middle of the alpha-gutta-percha. This produces good results in thin and curved canals but not in wide canals (LARES & ELDEEB 1990). In one study, no voids were found in specimens filled by Thermafil at any level after sectioning them 1.5 mm, 3 mm and 4.5 mm from the root apex (GENCOGLU et al. 2002). SCHILDER et al. (1985) postulated that vertical pressure must be applied in all warm gutta-percha techniques to compensate the volume changes. He also stated that when heating gutta-percha to a higher temperature than 45°C, phase displacement will cause shrinkage, independent of the types of gutta-percha. We suggest that methods for the compensation of shrinkage in root canal obturation should be evaluated.

In conclusion, we have found that under the conditions of the present study, commercial gutta-percha showed less shrinkage than alpha- and beta-gutta-percha. This means, since sealer must be used with commercial gutta-percha in root canal filling, it should also be used with alpha- and beta-gutta-percha of the Multifill system. Furthermore, the shrinkage of commercial gutta-percha observed in our study was higher than could be assumed from former studies. The design of the present study should be used to investigate the shrinkage behaviour of other obturation materials such as Resilon (Epiphany; Pentron, LLC Wallingford, USA, and RealSeal; SybronEndo, Orange, USA).

Zusammenfassung

Ziel der vorliegenden Untersuchung war der Vergleich der Schrumpfung der alpha- und beta-Guttapercha des Multifill-Systems mit handelsüblicher Guttapercha. Zehn Guttapercha-Blöcke wurden für jede der drei Sorten verwendet. Mit dem optischen Triangulationsverfahren wurde die Schrumpfung gemessen. Speckle Pattern Shearing Interferometrie wurde verwendet, um Lufteinschlüsse und Materialfehler auszuschliessen. Die drei Guttapercha-Sorten wurden auf 90°C erhitzt und anschliessend auf 35°C heruntergekühlt, während die Schrumpfung gemessen wurde. Die Schrumpfung der handelsüblichen Guttapercha war geringer (6,5%) als die von alpha-Guttapercha (7,2%) und von beta-Guttapercha (7,3%, $p = 0,0051$). Auch zwischen alpha- und beta-Guttapercha wurde ein signifikanter Unterschied ($p = 0,0093$) festgestellt. Im Bereich zwischen 45°C und 40°C zeigte sich bei alpha- und beta-Guttapercha die grösste Schrumpfung (2,2% bzw. 2,1%/5°C). Die handelsübliche Guttapercha zeigte ihre stärkste Schrumpfung zwischen 55°C und 40°C (1,1%/5°C). Insgesamt war die Schrumpfung von allen drei Guttapercha-Sorten höher als durch die Ergebnisse früherer Studien angenommen.

Résumé

Le but de l'étude était de comparer la contraction de gutta-percha alpha et bêta du système Multifill avec celle de la gutta-percha commerciale. Dix blocs de gutta-percha de chacun des trois types ont été utilisés.

L'absence de toute inclusion d'air et de déficiences de matériau dans les spécimens était assurée par «*Speckle pattern shearing interferometry*». La méthode de triangulation optique a été appliquée pour mesurer la contraction. Les trois types de gutta-percha ont été examinés après chauffage à 90 °C suivi d'un refroidissement à 35 °C. La gutta-percha commerciale montrait moins de contraction (6,5%) que la gutta-percha alpha (7,2%) et la gutta-percha bêta (7,3%) ($p = 0,0051$ pour les deux comparaisons; selon le «*signed rank test*» de Wilcoxon). Entre 45 °C et 40 °C les gutta-percha alpha et bêta ont révélé la contraction la plus importante (2,2%/5 °C et 2,1%/5 °C, respectivement). La gutta-percha commerciale montrait la plus grande contraction (1,1%/5 °C) dans la zone entre 55 °C et 40 °C. De manière générale, la contraction inhérente aux trois types de gutta-percha était supérieure à celle constatée dans des études précédentes.

References

COHEN B D: An investigation into the relative merits of some endodontic filling systems. MSc Thesis. Manchester, UK: University of Manchester (1984)

COHEN B D, COMBE E D, LILLEY J D: Effect of the thermal placement techniques on some physical properties of gutta-percha. Int Endod J 25: 292–296 (1992)

COMBE E C, COHEN B D, CUMMINGS K: Alpha- and beta-forms of gutta-percha in products for root canal filling. Int Endod J 34: 447–451 (2001)

DONLEY D L, WELLER R N, KULILD J C, JURCAK J J: In vitro intracanal temperatures produced by low- and high-temperature thermoplasticized injectable gutta-percha. J Endod 17: 307–309 (1991)

DU LAC K A, NIELSEN C J, TOMAZIC T J, FERRILLO P J JR, HATTON J F: Comparison of the obturation of lateral canals by six techniques. J Endod 25: 376–380 (1999)

FRIEDMAN C E, SANDRIK J L, HEUER M A, RAPP G W: Composition and physical properties of gutta-percha endodontic filling materials. J Endod 3: 304–308 (1977)

GENCOGLU N, GARIP Y, BAS M, SAMANI S: Comparison of different gutta-percha root filling techniques: Thermafil, Quick-fill, System B, and lateral condensation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 3: 333–336 (2002)

GILHOOLY R M, HAYES S J, BYRANT S T, DUMMER P M: Comparison of cold lateral condensation and a warm multiphase gutta-percha technique for obturating curved root canals. Int Endod J 33: 415–420 (2000)

GISH S P, DRAKE D R, WALTON R E, WILCOX L: Coronal leakage: bacterial penetration through obturated canals following post preparation. J Am Dent Assoc 125: 1369–1372 (1994)

GRASSI M D, PLAZEK D J, MICHANOWICZ A E, CHAY I C: Changes in the physical properties of the Ultrafil low-temperature (70 degrees C) thermoplasticized gutta-percha system. J Endod 15: 517–521 (1989)

HUNG Y Y, TAYLOR C E: Speckle-shearing interferometric camera – a tool for measurement of derivatives of surface-displacement. Proc Soc Photo-optical Instr Engin 41: 169–175 (1973)

KHAYAT A, LEE S J, TORABINEJAD M: Human saliva penetration of coronally unsealed obturated root canals. J Endod 19: 458–461 (1993)

LARES C, ELDEEB M E: The sealing ability of the Thermafil obturation technique. J Endod 16: 474–479 (1990)

LEE C Q, CHANG Y, COBB C M, ROBINSON S, HELLMUTH E M: Dimensional stability of thermosensitive gutta-percha. J Endod 23: 579–582 (1997)

LEENDERTZ A, BUTTERS J N: An image-shearing speckle-pattern interferometer for measuring bending moments. J Phys E: Sci Instrum 6: 1107–1110 (1973)

MALAGNINO V A, PASSARIELLO P, GALLOTTINI L: Analisi della tecnica di otturazione canalare con guttaperca multiphase secondo Mc Spadden. G Ital Endod 1: 23–32 (1997)

MARCHIANO J, MICHAILESCO P M: Dental gutta-percha: chemical composition, x-ray identification, enthalpic studies, and clinical implications. J Endod 15: 149–153 (1989)

MCSPADDEN J T: Multiphase gutta-percha obturation technique. Dent Econom 83: 95–97 (1993)

NISS H, JEPSEN S, GRIESINIGER H R, ALBERS H K: Thermoplastische und konventionelle Guttapercha-Wurzelkanalfülltechniken. Dtsch Zahnärztl Z 51: 627–630 (1996)

OLIVER C M, ABBOTT P V: Correlation between clinical success and apical dye penetration. Int Endod J 34: 637–644 (2001)

SCHILDER H: Filling root canals in three dimensions. Dent Clin North Am 11: 723–744 (1967)

SCHILDER H, GOODMANN A, ALDRICH W: The thermomechanical properties of gutta-percha. Part V. Volume changes in bulk gutta-percha as a function of temperature and its relation to molecular phase transformation. Oral Surg Oral Med Oral Pathol 59: 285–296 (1985)

STEINCHEN W, KUPFER G, YANG L X, MÄCKEL P: Dynamisch belastete Bauteile zerstörungsfrei prüfen. Materialprüfung 3: 91–95 (1997)

STEINCHEN W, YANG L X, KUPFER G, MÄCKEL P, VÖSSING F: Digitalshearography for strain measurement: an analysis of measuring errors. SPIE's 43rd Annual Meeting, Proceedings of SPIE, San Diego, California, USA (1998)

WU M K, WESSELINK P R: Endodontic leakage studies reconsidered. Part I. Methodology, application and relevance. Int Endod J 26: 37–43 (1993)