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RESEARCH AND EDUCATION

Evaluating the stability of extended-pour alginate impression materials by using an optical scanning and digital method

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ABSTRACT

Statement of problem. The dimensional stability of alginate dental impressions is a key factor for the reliability of delayed gypsum pouring and digital scanning. However, studies of the dimensional stability of alginates with conventional methods that consider the dimensional variations of large impressions are lacking.

Purpose. The purpose of this in vitro study was to investigate and compare 2 digital methods for the analysis of dimensional stability of large impressions made with 5 different extended-pour alginates and to assess dimensional stability up to 5 days.

Material and methods. Impressions of a simplified master maxillary model were made with Alginoplast, Blueprint, Hydrogum 5, Orthoprint, and Phase Plus and then analyzed at different time points. Digital scans of the alginate impression surfaces were obtained with a desktop scanner and analyzed by evaluating the linear measurements between reference points and by using a novel method that consists of the analysis of the entire scanned surface to evaluate the expansion and contraction of the impressions.

Results. The first method revealed that the dimensional changes did not exceed 0.5%, with the exception of Phase Plus at day 3 (-0.6 ±0.7%), and the average dimensional variation was always lower than or equal to 0.2 mm. Blueprint was the most stable material (-0.2 ±0.6%). The second method revealed dimensional variations always lower than 0.03 mm and confirmed Blueprint as the best performing material (0.001 ±0.006 mm) and Phase Plus the worst (-0.019 ±0.006 mm).

Conclusions. Both the methods used to evaluate alginate stability showed that the analyzed materials remain stable over time; the dimensional variations showed a similar trend, with differences in the absolute values depending on the applied method. Linear measurements are affected by the operator and choice of reference points; however, by evaluating the average variations of the entire structure surfaces, local variations should be minimized. The evaluation of the average variations with the second method offers the advantage of a rapid visual representation of these variations. (J Prosthet Dent 2020;■:■-■)

Irreversible hydrocolloid, or alginate, represents one of the most used materials for impression making because of its cost effectiveness, adequate precision, ease of handling, good physical properties, and good patient acceptability.[1-3] In spite of these advantages, its low dimensional stability over time is a critical drawback. Depending on the storage conditions, alginate impressions can undergo shrinkage or swelling in minutes or hours if the structure loses (syneresis) or gains (imbibition) water. Thus, it is necessary to pour impressions immediately, although practical considerations may lead to their being stored for a time. Extended-pour alginates were developed to deal with the instability of conventional alginate impression materials and, if adequately stored, allow gypsum pouring to be delayed for a few days.[4,5]

The effects of storage conditions (temperature, humidity, and presence of water) and of disinfecting

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Clinical Implications

The computational analysis of the dimensional variations of large impressions is a reliable method for the unbiased evaluation of irreversible hydrocolloid stability. Among the materials tested, Blueprint and Orthoprint were the most stable materials.

procedures on the stability of alginate impression materials have been evaluated. The most common recommendation is to pour or scan the impression immediately for best accuracy, but depending on the material and with the recommended procedures of disinfection and storage, the procedures can be delayed from hours up to a few days.[3,6-10]

The analysis of the dimensional stability of alginates has usually been based on the American Dental Association (ADA) specifications and International Standards Organization (ISO) standards, which do not specify the acceptable percentage of dimensional variation for irreversible hydrocolloids, but only for elastomeric materials.[4] The accuracy analysis of alginates, as described in ADA standards, is based on the evaluation of the material ability to correctly reproduce specific lines impressed on a small mold.[2,9] This strategy, however, might not be the best way to evaluate the stability of large impressions, and it might be better to simulate an oral arch with specific models to consider the complexity of 3D changes.[4,8] Indeed, alginate impression materials may reproduce details with adequate accuracy, but when large impressions are analyzed, shrinkage and swelling might occur, thus altering the distances from the details. This might not be detected by the conventional methods of stability analysis.[4,11]

Alternative methods of producing dentulous and edentulous casts from alginate impressions, for example, with intraoral or laboratory scanners or with cone beam computed tomography (CBCT), have been described.[12,13] Furthermore, digital casts may be printed with rapid prototyping techniques[14] and then used to evaluate the accuracy and stability of alginate impressions or to evaluate the precision and reliability of CBCT and intraoral scanners.[1,12,15,16] In the case of a delayed scanning procedure, alginate impressions must remain stable until the time the scan is acquired.[16]

The purpose of the present in vitro study was to explore digital methods of evaluating the stability of large impressions made with commercially available extended-pour alginate impression materials: Alginoplast, Blueprint, Hydrogum 5, Orthoprint, and Phase Plus. The impressions were stored at room temperature in a humid environment and then scanned with a desktop scanner at different time points (up to 4 days); the scans were analyzed by using 2 methods based on linear and 3D digital measurements. The null hypotheses were that the extended-pour alginates would not display significant dimensional alteration and that no differences would be found between the 2 digital methods of stability analysis.

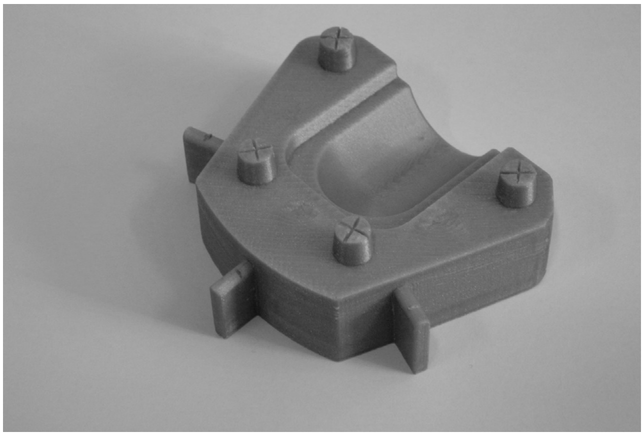

Figure 1. Master model used for impression procedure.

MATERIAL AND METHODS

Following an approach similar to that of Sedda et al,[11] impressions were made of a master model (Fig. 1) under simulated clinical conditions. The master model was prepared by modifying a standardized quadrangular plate digital model. Four cylinders engraved with a cross were added on the upper surface of the master model and used as reference points for the measurements. Three stops were added to the lateral surface of the model (2.5 mm below the upper surface) to standardize the impression procedure and the thickness of the impression materials. The modified digital model was used to print the master model from polylactic acid with a 3D printer (Ultimaker 3 Extended; Ultimaker, Ltd).

Table 1 reports the characteristics, the conditions of preparation and storage, and the applications, as provided by the manufacturer of the alginates analyzed. These were mixed at room temperature with distilled water and a power mixer, (Hurrimix2; Zhermack, Ltd). Powder-liquid proportions provided by the manufacturer of each material were followed (Table 1). For each material, 5 impressions were made in an impression tray and then stored and scanned at different time points (0, 1, 2, 3, and 4 days).

Single-use transparent perforated plastic impression trays were used for the maxilla (size 3; Coltène). Three perforations were made in the trays, corresponding with the 3 stops on the master models, to standardize the impression making procedure. The same operator (I.K.)

Table 1. Characteristics of tested alginates

Material	Manufacturer	Storage	Applications
Alginoplast	Kulzer GmbH	2 d in sealed envelope at room temperature with 100% humidity	Diagnostic casts for removable dental prostheses and antagonist arch
Blueprint	Dentsply Sirona	5 d wrapped in a humid cloth and stored in a sealed polyethylene bag at room temperature	Diagnostic casts for orthodontic and opposing dentition, partial skeletal removable dental prosthesis without precision attachments, removable orthodontic appliances and splints, and temporary restorations
Hydrogum 5	Zhermack, Ltd	5 d after removal of water excess in a tightly sealed envelope at room temperature	Impressions for diagnostic casts, impressions for antagonists in fixed and removable prostheses
Orthoprint	Zhermack, Ltd	2 d after removal of water excess in a tightly sealed envelope at room temperature	Suitable for use in orthodontics even in presence of brackets, as well as for orthodontic diagnostic casts
Phase Plus	Zhermack, Ltd	2 d after removal of water excess in a tightly sealed envelope at room temperature	Suitable for impressions for diagnostic casts

made the impressions by using the master model previously wetted with distilled water to facilitate removal of the impression tray. Impressions were disinfected with a sodium hypochlorite solution (0.5 % v/v in distilled water) for 5 minutes[17] and rinsed with distilled water. Impression scans were acquired with a structured-light 3D scanner (resolution, 5 μm; scan integration interval, 15 degrees; 2 acquisition averaged; SinergiaScan Advanced Plus; Nobil Metal, Ltd). Excess water was gently removed with compressed air. A software program (DentalScan 7.0; Nobil Metal, Ltd) was used to export the scans as triangular mesh surfaces. After each scanning procedure, impressions were immediately stored in sealed nylon bags with a humid cloth[18] and stored at room temperature for the duration of the experiment. The triangular meshes derived from the scanning procedure were analyzed with 2 different methods to evaluate the dimensional variation of the impressions over time.

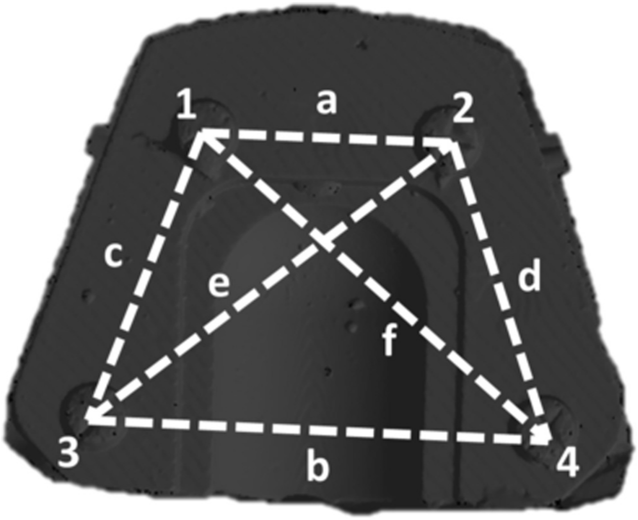

Figure 2. Linear measurements revealed with netfabb.

The first method, netfabb (NF) was based on the linear measurements between the different reference points made on each scan at the different time points (Fig. 2) by using a software program (netfabb; Autodesk, Inc). Each measurement, made at days 1 to 4, was compared with the measurement at day 0; the variation of the specific measurement (a, b, c, d, e, and f) for each scan with respect to day 0 was determined. The variations of linear measurements for each time point were used to calculate an average variation in terms of percentages and of linear distances.

The second method, CloudCompare (CC) was based on the evaluation of surface variations of the entire impressions, evaluated after the superimposition of the scans recorded at day 1 to 4 (compared surfaces) on the scans recorded at day 0 (reference surface) for each impression replica by using a software program (CloudCompare Omnia GPL; EDF). After coregistration, the software computed the distances between each point of the compared surface with respect to the reference surface. The software generated a distribution of distances (Fig. 3) where green values represent a concordance between the surfaces and where red or blue values represent expansions or contractions of the compared surface with respect to the reference surface.

Statistical analysis was performed with a statistical software program (Origin; OriginLab Corp). Measurement values derived from both methods were tested for normal distribution with the Kolmogorov-Smirnov test. In both cases, the absolute dimension variations on the same day between the various materials and for the same material at the different time points were compared (α=.05). Homoscedasticity was respected for comparison among materials at the same time point for the NF method and for day 3 and 4 for the CC method; it was also respected for comparison between the time points for the same material for the CC method. These data were therefore compared by applying a Tukey-corrected ANOVA test. The other data were analyzed with a Kruskal-Wallis test followed by the Mann-Whitney test with Bonferroni correction for paired comparisons.

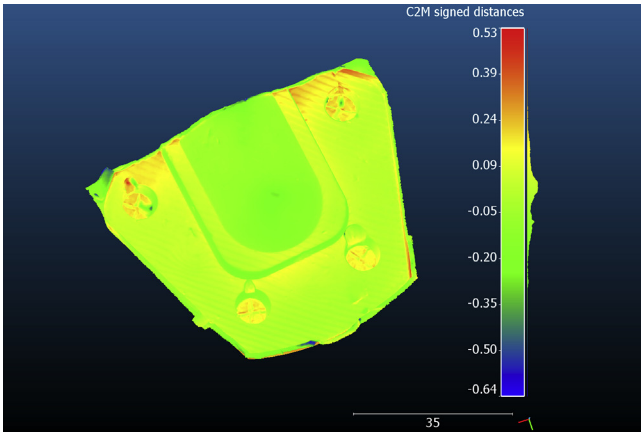

Figure 3. Displacements of Compared surface (days 1-4) with respect to reference surface (day 0) as computed by CloudCompare and represented as color scale going from expansions (*red* values) to contractions (*blue* values).

RESULTS

Table 2 shows the average values of dimensional variations in percentages as measured with the NF method: negative values represent a reduction and positive values an increase of the linear measurements. Except for Orthoprint alginate at day 1, a contraction was observed with respect to day 0. The average dimensional changes with respect to day 0 did not exceed 0.5 %, except for Phase Plus at day 3.

The values of dimensional variations with respect to day 0 were used to calculate the average dimensional variation of the entire structure for each material and time point (Fig. 4). The average dimensional variation was lower than or equal to 0.2 mm for all the materials.

Blueprint and Orthoprint alginates did not show any statistically significant difference among the impressions, indicating the stability of these materials. The dimensional variations of Hydrogum 5 alginate were statistically significant only at day 2. The mean ±standard deviation dimensional variation with respect to day 0 was -0.15 ±0.21 mm (P<.001). The dimensional variations for the remaining alginates were statistically significant at all time points for Alginoplast (day 1, -0.12 ±0.25 mm; day 2, -0.17 ±0.24 mm; day 3, -0.20 ±0.24 mm; day 4, -0.20 ±0.21 mm) and at day 1 (-0.11 ±0.23 mm), 3 (-0.21 ±0.28), and 4 (-0.17 ±0.27 mm) for Phase Plus alginate; P values are reported in Table 3.

Regarding the differences among the dimensional variations of the materials at the same time point, these were detectable only between Blueprint and Phase Plus at day 3 (Blueprint, -0.01 ±0.31 mm; Phase Plus, -0.21 ±0.28 mm; P=.037) and between Alginoplast and Blueprint at day 4 (Alginoplast, -0.20 ±0.21 mm; Blueprint, -0.01 ±0.23 mm; P=.040); in both cases, the dimensional variations for Blueprint alginate were smaller than those of the other materials, indicating that this material was the most stable overall.

Table 2. Mean ±standard deviation dimensional variations at day 1 to 4 measured with netfabb software; reported as percentage with respect to dimension at day 0

Material	Day 1	Day 2	Day 3	Day 4
Alginoplast	-0.3 ±0.6	-0.5 ±0.6	-0.5 ±0.6	-0.5 ±0.5
Blueprint	-0.2 ±0.6	-0.0 ±0.6	-0.1 ±0.7	-0.1 ±0.6
Hydrogum 5	-0.1 ±0.5	-0.4 ±0.6	-0.2 ±0.6	-0.3 ±0.6
Orthoprint	0.1 ±0.6	-0.1 ±0.6	-0.1 ±0.6	-0.2 ±0.7
Phase Plus	-0.3 ±0.5	-0.4 ±0.7	-0.6 ±0.7	-0.4 ±0.6

The average values of dimensional variation for each material and time point as determined with the CC method are reported in the histogram in Figure 5. Positive and negative values indicate expansion and contraction of the structures. The average values of dimensional variations computed on the entire surface were always lower than 0.03 mm; moreover, for Alginoplast, Hydrogum 5, and Phase Plus, with respect to the data reported in Figure 4, dimensional variations increased over time.

Statistical analysis performed to investigate the variations over time in terms of expansion and contraction showed that for Blueprint and Orthoprint alginates, differences among the impression scans over time were not statistically significant, confirming the stability of these materials from an analysis of linear dimensional changes. For Alginoplast and Phase Plus alginates, the dimensional variations at day 4 were significantly higher than the dimensional variations at day 1 (Alginoplast: day 1, 0.000 ±0.003 mm; day 4, -0.007 ±0.003 mm, P=.049; Phase Plus: day 1, -0.010 ±0.004 mm, day 4, -0.019 ±0.006 mm, P=.041), demonstrating the instability of these materials. The analysis of the differences among the materials at the same time point showed that the impression changes in terms of dilatation and contractions at day 3 and at day 4 for Hydrogum 5 (day 3, -0.020 ±0.010 mm; day 4, -0.023 ±0.006 mm) and Phase Plus (day 3, -0.016 ±0.005 mm; day 4, -0.019 ±0.006 mm) were similar (P>.05) and significantly higher with respect to the other alginates; P values are reported in Table 4.

DISCUSSION

The dimensional variations of alginate impressions were evaluated from digital scans of the impressions measuring linear distances (NF method) and also by using a novel approach based on the superimposition of the impression scans and the evaluation of the entire impression surfaces changes (CC method). The analyses with both methods led to the acceptance of the first null hypothesis regarding the stability of the materials, which

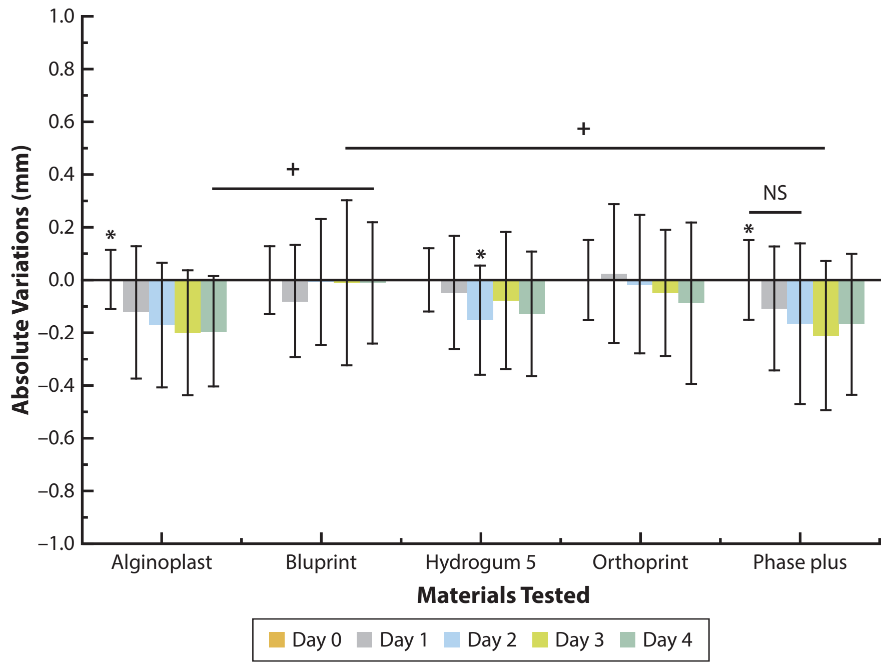

Figure 4. Dimensional variation of linear measurements made with netfabb software, reported as absolute average values for day 1 (gray), day 2 (light blue), day 3 (yellow green) and day 4 (olive) compared with day 0. Variations at day 0 are equal to 0; standard deviations indicate linear measurement variability at day 0. Symbols represent statistically significant differences intra- (*) or inter- (+) material.

did not show dimensional alterations up to 4 days, and to the rejection of the second null hypothesis, as the 2 methods tested showed differences in the analysis of alginate stability.

The NF method showed that all the alginates underwent dimensional changes lower than 0.5% with respect to the dimensions measured at day 0, except Phase Plus at day 3. In terms of the absolute values derived from the obtained measurements, the dimensional variations were always lower than 0.2 mm, a value that has been considered acceptable for the use of impressions and digital casts.[12,14,16]

The analysis of dimensional variations performed with the CC method showed some differences with respect to the NF method: the average dimensional variations were, for all the materials tested, lower than 0.03 mm; a trend of structure shrinking over time for Alginoplast, Hydrogum 5; and Phase Plus was detected, with statistically significant differences for alginate and Phase Plus. Despite these differences, the CC method determined that all the materials tested were stable and suitable for delayed gypsum pouring or digital scanning.[12,14,16] Blueprint and Orthoprint, as determined by the NF method, showed the best stability over time.

Accurate impressions depend on their stability, which in turn depends on storage conditions and disinfection procedures.[4,6] Impression stability is essential for the accurate and precise preparation of diagnostic casts and production of dental appliances.[1,4,11] A critical issue regarding the evaluation of irreversible hydrocolloid stability is the threshold values used to distinguish stable and unstable materials. Most of the studies follow ADA and ISO recommendations and analyze the ability of alginate to reproduce, with adequate accuracy, details traced on a mold (lines 25-, 50-, and 75-μm wide).[2,9] Other studies measured the dimensional change (for example, with calipers or optical microscopy) and considered a material stable if the dimensional variations were lower than 0.1% to 0.8%; the commonly accepted threshold value has been 0.5%.[4,8] The results obtained with both methods in the present study determined that the materials tested were stable as per the previously described criteria.[2,4,8,9]

Table 3. Statistical analysis results, expressed as *P* values, comparing Alginoplast and Phase Plus dimensional variations with day 0

Material	Day 1	Day 2	Day 3	Day 4
Alginoplast	.001	.007	.001	.001
Phase Plus	.007	>.05	<.001	.001

Data analyzed with Kruskal-Wallis test followed by Bonferroni corrected Mann-Whitney test for paired comparison.

Regarding the methods used, digital scans allowed a direct and less-biased intraspecimen comparison, avoiding gypsum pouring (with the consequent dimensional change) and avoided excessive manipulation of the impressions. Moreover, the analyses performed on the digital casts showed improved precision and accuracy, which are not ensured when manual methods such as calipers are adopted.[4,12]

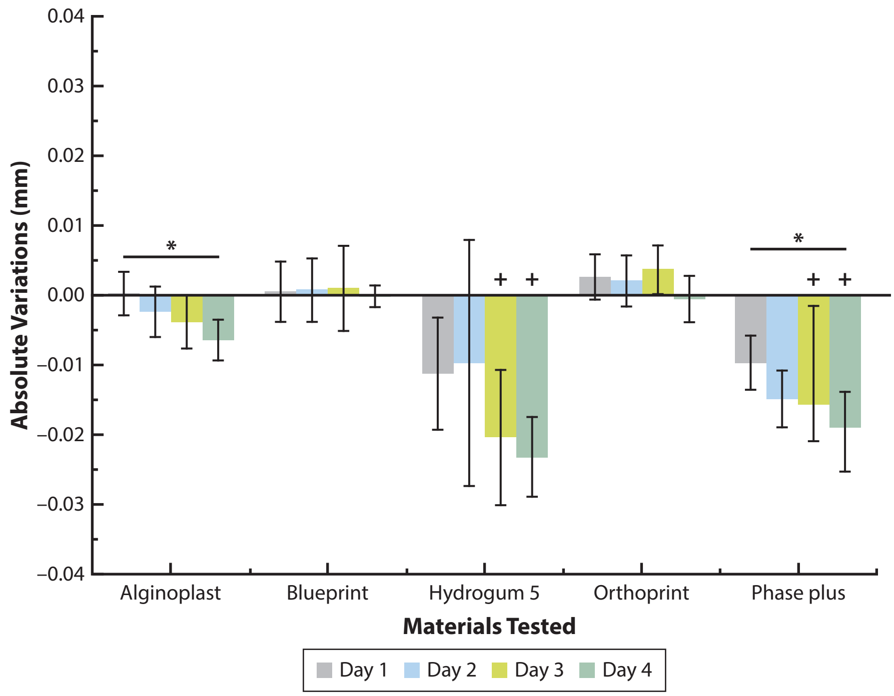

Figure 5. Average value of surfaces expansions and contractions computed with CloudCompare, at day 1 (gray), day 2 (light blue), day 3 (yellow green), and day 4 (olive) compared with surfaces at day 0. Symbols represent statistically significant differences intra- (*) or inter- (+) material.

Table 4. Statistically significant *P* values of impression changes at day 3 and day 4 with respect to day 0 for Hydrogum 5 and Phase Plus compared with Aginoplast, Blueprint, and Orthoprint

Statistically Significant Comparisons	Day 3	Day 4
Hydrogum 5–Alginoplast	.003	<.001
Hydrogum 5–Blueprint	<.001	<.001
Hydrogum 5–Orthoprint	<.001	<.001
Phase Plus–Alginoplast	.046	.002
Phase Plus–Blueprint	.003	<.001
Phase Plus–Orthoprint	.001	<.001

Data where analyzed by applying Tukey-corrected ANOVA test.

The linear measurements of the NF method are more dependent on the operator and on the choice of the reference points. The discrepancies between the 2 methods could be ascribed to the use of reference points for linear measurements (the cross symbols on the 4 cylinders), which were more prone to dimensional variations than the rest of the impression structure. Variations with the CC method were low over the entire structure. Alginate impressions may have different accuracy in different regions; thus, it is important not only to evaluate the overall dimensional changes but also the reproduction of surface details.

Limitations of the present study include that the digital scans of the impressions were evaluated rather than evaluating the impressions directly. Future studies could focus on comparing digital scan analysis with the analysis of the weight variation of alginate impressions or with the analyses of CBCT scans of the alginate impressions.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. All the alginates tested appeared to be suitable for delayed pouring up to 4 days, with dimensional changes almost always lower than or equal to accepted thresholds.
2. Computing the average dimensional variations of digital scans can be a rapid and reliable method of detecting average dimensional changes, but more importantly, if a visual representation of the structure variation can be obtained, the analysis of the accuracy of the alginate impression materials can focus on specific details.

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Davide Porrelli: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Federico Berton:** Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Alvise Camurri Piloni:** Data curation, Formal analysis, Writing - original draft. **Ivana Kobau:** Conceptualization, Data curation. **Claudio Stacchi:** Investigation. **Roberto Di Lenarda:** Supervision. **Roberto Rizzo:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing.

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