Journal of Dental Sciences 19 (2024) S149—S155

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

Trueness comparison of intraoral scans for diverse arch lengths in pediatric dental models

Chin-Yun Pan [a,b,c†], Min-Yan Chen [a†], Chih-Te Liu [a,d], Kai-Chun Cheng [d], Jen-Hao Chen [a,d], Chun-Cheng Hung [d], Ting-Hsun Lan [a,d*]

[a] *School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*
[b] *Department of Dentistry, Kaohsiung Municipal Siaogang Hospital, Kaohsiung, Taiwan*
[c] *Division of Orthodontics, Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung Medical University, Kaohsiung, Taiwan*
[d] *Division of Prosthodontics, Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan*

Received 10 July 2024; Final revision received 31 July 2024
Available online 10 August 2024

KEYWORDS
Spaced arch;
Trueness;
Arch length;
Intraoral scanner

Abstract *Background/purpose:* Spacing between teeth is a common trait across different stages of dentition. With the tide of the digital impression, the scanning trueness of the intraoral scanner (IOS) is a hot subject. This study aimed to determine the correlation between the level of the spaced dentition and trueness of the intraoral scanning.
Materials and methods: Four arch lengths of deciduous tooth models (spacing Model 1, Model 2, Model 3, Model 4 = 0, 1, 2, 3 mm; maxillary arch length = 73.268, 81.922, 90.776, 97.698 mm; mandibular arch length = 69.092, 76.160, 86.228, 94.344 mm) were designed to measure trueness via an IOS. Statistical analysis included one-way analysis of variance followed by post hoc Tukey tests for comparisons of the data.
Results: The trueness varied across different levels of spacing, with the highest deviation observed between intraoral and desktop scans in Model 3, followed by Model 4, Model 2, and Model 1 in the maxillary arch. In the mandibular arch, the sequence of deviation from highest to lowest was Model 4, Model 3, Model 1, and Model 2. Significant differences were observed among these models in both the maxilla and mandible ($P < 0.001$).

* Corresponding author. School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, 100 Shin-Chuan 1st Road, Sanmin District, Kaohsiung 807378, Taiwan.
E-mail address: tinghsun.lan@gmail.com (T.-H. Lan).
† These two authors made equal contributions to this manuscript.

https://doi.org/10.1016/j.jds.2024.07.041

Conclusion: In both the maxilla (2 mm spacing, arch length ≥81.922 mm) and mandible (3 mm spacing, arch length ≥86.228 mm), scanning accuracy decreases with longer arch lengths. This indicates that as arch length increases, so does the deviation in scanning accuracy. Therefore, the clinician should notice the deviation when using IOSs for the spaced cases.

Introduction

Digital dentistry has gained significant popularity in recent years with the advancement of science and technology. Many valuable technologies are coming out one after another. Among these techniques, intraoral scanners (IOSs) were the next wave of technology that was embraced by the profession.[1] The IOS mainly captures continuous images of the patient's dental arch by irradiating the teeth with light or laser. It generates a point cloud of the obtained data through subsequent reconstruction software. These point clouds are triangulated to provide the meshes required for surface reconstruction, and the three-dimensional reconstruction of the surface is performed to obtain a virtual model of the patient's dental arch.[2] Digital impressions have advantages over conventional impressions, such as more minor patient discomfort, efficiency, and simplified clinical procedures.[3] Nowadays, more significant accuracy has been demanded in 3D digital models. There are increasingly more applications in the dental industry, and these digital models are applied as diagnostic tools for planning treatments and fabricating dental appliances, all requiring precise accuracy.[4,5] Multiple factors influence the accuracy of the IOS used clinically, such as the type of IOS, the scan strategies,[2,6–8] scanning environments,[9,10] gestures during scanning,[11] scan distance and depth of field would affect the final results of scan images.[12] Recording full-arch digital data is helpful for clinical treatment; however, Medina-Sotomayor[13] stated that there was a low scan deviation in a single crown, but full-arch scanning still had its discrepancies and limitations.

Spacing is a dental irregularity characterized by gaps between teeth and a lack of points of contact between teeth.[14,15] The incidence of spacing in primary dentitions ranges from 98% to 42.9%.[16] Most authors report an incidence of around 90%, and the absence of spacing would cause a severe risk of crowding in the permanent dentition.[16] The regular development of the permanent dentition depends on the space between the deciduous dentition.[14,16] These deciduous teeth spacing can compensate for the tooth size difference between the primary and permanent teeth. Primary dentition spacing is a prerequisite and represents an essential feature of later permanent tooth eruption and occlusal establishment.[17,18] The value of deciduous dentition spacing has always been a hot topic in the development of permanent dentition.[19] The spacing occurs in the deciduous dentition and is observed in the permanent dentition.[20] In some studies, Gkantidis et al.[16] concluded that the most frequent spacing is mainly due to greater jaw size and not to smaller teeth. The maxillary arch increases in mixed and permanent dentition due to increased inter-canine width, deciduous intermolar width, and first permanent molar width.[21] In the mandibular arch, decreased arch length in the mixed and permanent dentition stages due to loss of leeway space via uprighting the incisors and mesial movement of the first permanent molars.[20] The average arch length increases by 1 mm and decreases by 4 mm between six and eighteen years of age in the maxillary and mandibular arch, respectively.[20] Thus, the space discrepancy will also change with different dentition stages. And when the space discrepancy is positive, the dentition is spaced. As the space discrepancy increases, the total spaces between the teeth become larger. The transition from the primary to the permanent dentition period influences dental arch length.[20]

Previous studies in adults[22] pointed out that the scanning deviation in the maxillary arch would be lower than that in the mandible arch. Other studies have noted that the scanning deviation in anterior segment teeth is lower than in posterior segment teeth.[23,24] However, literature seldom evaluates the scan deviation for the pediatric dental arch. Holsinger et al.[25] showed a retrospective analysis of maxillary anterior pediatric zirconia crowns for esthetic prosthesis in pediatric dentistry, and parental satisfaction with zirconia crowns is high. Verma et al.[26] mentioned that primary anterior zirconia crowns were more popular with parents than strip crowns. So, using IOS to capture pediatric dental arch images and design the primary zirconia crown would be increasingly popular. In this study, four different arch-length pediatric models that were scanned using IOS, and the trueness of four dental arches was compared. The study aimed to determine whether the different arch lengths in deciduous tooth models affect the trueness of scanning.

Materials and methods

Models set up

Four models were created and printed for this study, including one standard model and three spaced variants. These models were scanned using an E4 Dental Scanner (3Shape, Copenhagen, Denmark) to generate initial STL files. To mimic clinical conditions, all models were mounted on a Nissin Simple Manikin II (Nissin Dental Products Inc., Kyoto, Japan), which was positioned on a dental chair. The intraoral scanning was performed using the VIRTUO VIVO system (Dentalwings, Montreal, Canada).

Arch length can be quantified by breaking the dental arch into measurable segments approximated by straight lines, or by tracing the occlusal line with a wire, which is then straightened to facilitate measurement.[27,28] Fig. 1 shows four dental models with different arch lengths: Model 1 (a standard model without spacing between any two of 10 deciduous teeth), Model 2 (a spaced model with 9 evenly 1 mm spacing between any two of 10 deciduous teeth), Model 3 (a spaced model with 9 evenly 2 mm spacing between any two of 10 deciduous teeth) and Model 4 (a spaced model with 9 evenly 3 mm spacing between any two of 10 deciduous teeth), respectively, the dimension of each model was presented in Table 1.

The G power analysis was used to estimate the required sample size; assuming four test groups, an effect size of 0.4, the probability of Type I (α) error of 0.05, and the power of 0.80. Sample size was thus determined to be 10 per group.

Scanning strategy

To scan the maxilla, the process began at the right second molar, following the occlusal surface to the left second molar and then back via the palatal surface, concluding with a scan of the buccal surface. For the mandible, scanning commenced at the occlusal surface of the right second molar, traversed longitudinally across the dental arch to the left second molar, and concluded along the lingual and buccal surfaces. The sequence and methodology for all operations were consistent, as depicted in Fig. 2.

An experienced right-handed dentist, familiar with the equipment, conducted all scans to ensure consistency and reliability. Each arch scan was completed in under 250 s to minimize variability, maintaining a consistent 10 mm distance between the scanner tip and the tooth surface during the scanning process. The environmental conditions—room temperature set at 22 °C, relative humidity at 60%, and standardized lighting—were controlled to further reduce variability. The same dentist performed all test scans using AI-enhanced scanning technology to eliminate discrepancies.

The scan data were analyzed using the "best-fit matching" and "cut view" features of the CAD software (Exocad DentalCAD; Exocad GmbH, Align Technology Inc., Santa Clara, CA, USA). These tools facilitated the assessment of discrepancies between the model's measuring points and the table scan file.

Table 1 Space analysis for four models (Model 1: a standard model without spacing, Model 2: a spaced model with evenly 1 mm spacing between each tooth, Model 3: a spaced model with evenly 2 mm spacing between each tooth, and Model 4: a spaced model with evenly 3 mm spacing between each tooth; Unit: mm).

Sample	Arch length	
	Maxillary arch	Mandibular arch
Model 1	73.268	69.092
Model 2	81.922	76.160
Model 3	90.776	86.228
Model 4	97.698	94.344

The accuracy of the spaced arches was evaluated by importing all STL files into three-dimensional analysis software (DentalCAD 3.0 Galway, exocad GmbH, DE Hessen, Darmstadt, Germany). The meshes from the IOS were aligned with the reference model from the desktop scanner to calculate the mean deviation (± standard deviation, SD), which was shown in Fig. 3 to be 0.088 mm.

Statistical analysis

Statistical analyses of differences between groups were conducted using one-way analysis of variance (ANOVA), followed by post hoc comparisons using the Tukey test. These analyses were performed using IBM SPSS Statistics for Windows, Version 20 (IBM Corp., Armonk, NY, USA). A *P*-value of less than 0.05 was considered statistically significant for all tests.

Results

The mean deviations of the four models in the maxilla and mandible are presented in Table 2. In the maxillary arch, the deviation values between intraoral scans and desktop scans were highest for Model 3 (0.052 ± 0.017 mm), followed by Model 4 (0.047 ± 0.020 mm), Model 2 (0.045 ± 0.012 mm), and Model 1 (0.040 ± 0.010 mm). In the mandibular arch, the deviations, from greatest to least, were Model 4

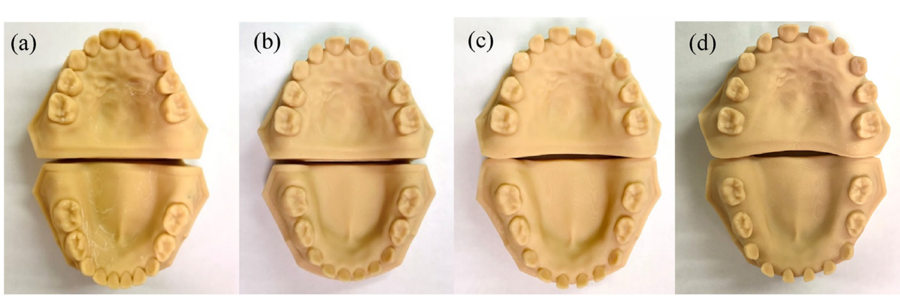

Figure 1 Four different spaced arches: (a) Model 1 (a standard model without spacing), (b) Model 2 (a spaced model with evenly 1 mm spacing between each tooth), (c) Model 3 (a spaced model with evenly 2 mm spacing between each tooth), and (d) Model 4 (a spaced model with evenly 3 mm spacing between each tooth).

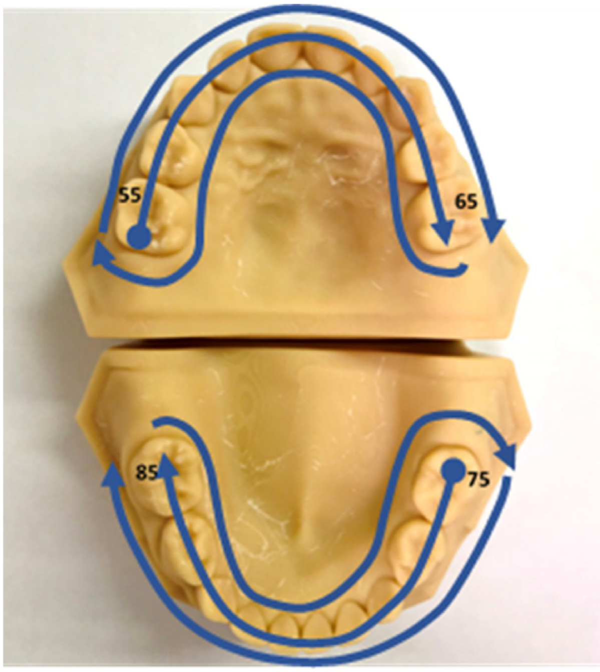

Figure 2 Scanning sequence used in this study.

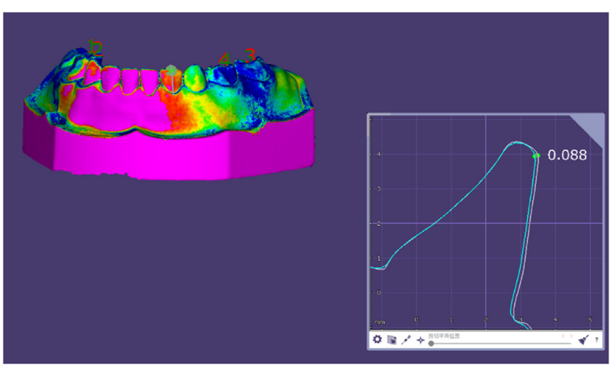

Figure 3 The maximum deviation in the operational Interface of analyzing software was 0.088 mm.

(0.088 ± 0.072 mm), Model 3 (0.062 ± 0.044 mm), Model 1 (0.052 ± 0.022 mm), and Model 2 (0.049 ± 0.021 mm).

The maxilla and mandible displayed significant differences across the four models ($P < 0.001$). Fig. 4 illustrates the superimpositions between the digital reference and the intraoral scan models, revealing increased deviations, particularly noticeable as a high percentage of pink in the right posterior region of the mandible.

Fig. 5 presents the deviations at various tooth positions in the maxilla for the four models. While positions 53, 61, 62, and 63 showed similar deviations across all models, significant differences were noted at positions 55, 54, 52, 51, 64, and 65 ($P < 0.05$). Fig. 6 details the deviations at different tooth positions in the mandible, indicating that Models 1, 2, and 3 exhibited similar deviation patterns across the examined positions. It is worth noting that the scanning deviations of Model 4 show a distinct trend among the four, which presents a gradual rise, especially at tooth positions 82, 83, 84, and 85 (the right posterior tooth region).

Discussion

The principal findings of this study indicate that the trueness between intraoral and desktop scanning systems for dental arches varies depending on the tooth size and arch length. In the maxillary arch, Model 3 exhibited the highest deviation values ($P < 0.001$), while Model 4 and Model 3 were not significantly different ($P > 0.05$). Model 4 showed the highest deviation values in the mandible, while Model 2, Model 3, and Model 1 showed a similar deviation in the maxilla ($P < 0.05$). These findings underscore the need for prudence when utilizing scanning technology for specific arch-length models due to potential variations in accuracy across different models. Currently, there is no established tolerance range for the deviation values of intraoral scanning in spaced dental arches. However, reducing these deviation values could potentially decrease dental treatment times. While this study offers valuable insights into the accuracy of scanning technologies, its conclusions are confined to the particular models and scanning methods

Table 2 The mean deviations of four models in the maxilla and mandible (Model 1: a standard model without spacing, Model 2: a spaced model with evenly 1 mm spacing between each tooth, Model 3: a spaced model with evenly 2 mm spacing between each tooth, and Model 4: a spaced model with evenly 3 mm spacing between each tooth; Unit: mm).

	Maxilla Value			Mandible Value		
	Mean ± SD	95% CI	P -Value	Mean ± SD	95% CI	P-Value
			<0.05*			<0.05*
Model 1	0.040 ± 0.009^{a}	(0.023, 0.075)		0.052 ± 0.022^{A}	(0.022, 0.128)	
Model 2	0.045 ± 0.012^{b}	(0.024, 0.090)		0.049 ± 0.021^{A}	(0.022, 0.153)	
Model 3	0.052 ± 0.017^{c}	(0.021, 0.108)		0.062 ± 0.044^{A}	(0.024, 0.261)	
Model 4	0.047 ± 0.020^{bc}	(0.016, 0.142)		0.088 ± 0.072^{B}	(0.022, 0.327)	

*One-way ANOVA (three independent groups).
*Multiple comparisons with post hoc Tukey test; different superscript letters in a column indicate statistical significance among groups ($P < 0.05$).

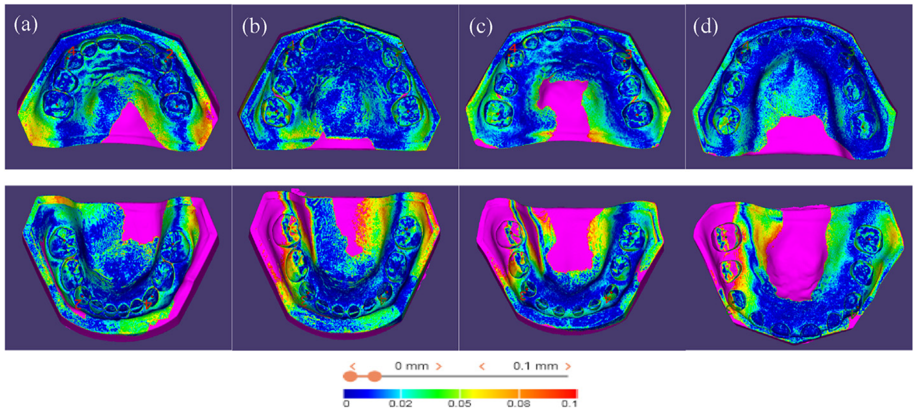

Figure 4 The superimpositions between digital reference models and digital intraoral scan models: (a) Model 1 (a standard model without spacing), (b) Model 2 (a spaced model with evenly 1 mm spacing between each tooth), (c) Model 3 (a spaced model with evenly 2 mm spacing between each tooth), and (d) Model 4 (a spaced model with evenly 3 mm spacing between each tooth).

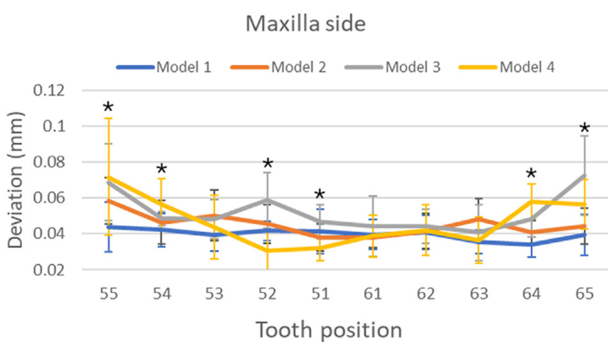

Figure 5 Deviations at different tooth positions among four models in the maxilla. (Symbol * indicated the statistical significance).

employed and may not be applicable to other contexts. Overall, this research emphasizes the necessity of acknowledging the limitations of scanning technology in clinical settings. Additionally, a longer arch length might cause repeated imaging. Accurate capturing of images and avoiding overlaying imaging was essential for the trueness of IOSs. Therefore, the longer the arch length in the oral cavity, the more angle and space need to be flipped on the scanning route. Moreover, excess movement of the scanner would influence the accuracy of capturing images and increase the scanning time. The error increased with the increase in the level of arch length. Therefore, it was reasonable that the level of the spaced arch has an apparent effect on trueness.

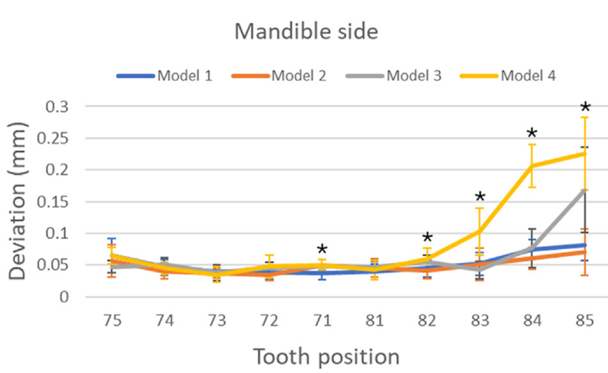

Figure 6 Deviations at different tooth positions among four models in the mandible. (Symbol * indicated the statistical significance).

There are significant differences between the maxilla and the mandible in both models. Model 3 has the lowest trueness in the maxilla, followed by Model 4, Model 2, and Model 1. The difference in the upper row of teeth may be caused by the machine itself, scanning sequence, and scanning gestures. Model 4 has the lowest trueness in the mandible, followed by Model 3, Model 1, and Model 2. Notably, the error value is relatively large in the right posterior teeth, especially in Model 4. Although the lower jaw was visible directly and more easily located and scanned than the upper jaw, the error value of the lower jaw was higher than the error value of the upper jaw in each model. This result may be deduced from the scanner overheating while scanning the lower jaw due to the scanning sequence. The statistical results showed a significant difference at the maxilla's tooth positions 55, 54, 52, 51, 64, and 65. The statistical results showed a significant difference at the mandible's tooth positions 71, 82, 83, 84, and 85. The scanning results show that the deviation between model 3 and model 4 in the posterior teeth area, revealing that the deviation in the posterior teeth increased with the dental arch length. These deviations are acceptable for ordinary children. However, when a child's dental arch length is relatively long (similar to that of an adult), there would be some accumulated errors in the posterior teeth of the mandible during oral scanning, presumably related to the errors caused by the machine and gestures. These results are consistent with previous studies.[11,28] It was also pointed out that the scanning deviation in the maxillary arch would be lower than that in the mandible arch.[23] Other studies have noted that the scanning deviation in anterior segment teeth is lower than in posterior segment teeth.[24,25] These discrepancies may stem from the inherent instability and movement experienced while operating the IOS. The construction of the 3D model often results in greater inaccuracies in the more curved regions of the dental arch, such as the premolars, canines, and the distal surfaces of the molars. These areas necessitate multiple angle adjustments during scanning, which can amplify errors.

Previous research has examined the clinical use of IOSs, comparing their accuracy with traditional impression methods. These studies indicate that IOSs provide more precise and reliable results in short-span areas. In pediatric dentistry, employing these scanners along with additional digital resources, such as white crowns, can enhance treatment effectiveness and accuracy. This integration not only speeds up the treatment process but also increases satisfaction among both patients and their parents. The results showed that more prominent spaced cases (spacing in maxilla $\geq$2 mm (or arch length $\geq$81.922 mm), spacing in mandible $\geq$ 3 mm (or arch length $\geq$86.228 mm)) using optical impression should consider the model's accuracy. In this case, a PMMA crown could be exported and validated in the mouth, and re-export the final product. Alternatively, for mild spacing (1 mm in the maxilla (arch length 73.268 mm) and less than 2 mm in the mandible (arch length 76.160 mm)), optical impressions are recommended for clinical application.

Once variations in tooth size and arch length are established, digital methods can be effectively utilized for clinical diagnosis and practice. Furthermore, ongoing advancements in IOS technology continue to enhance the precision and consistency of measurements. Exploring various scanning strategies also aids in optimizing diagnostic and treatment planning processes.

This study has certain limitations. It employed only one IOS and a single scanning strategy. Although dental models were mounted in a Nissin holder on a dental chair to mimic clinical posture, environmental factors such as saliva, blood, and changes in soft tissue were not accounted for, which could affect the outcomes. Future research would benefit from comparing various IOSs and examining their performance under different clinical conditions. Within the limitations of the present study, the trueness of the optical impression for the entire arch via one path in the full arch differed from the maxilla and mandible and depended on arch lengths. Both in the maxilla and the mandible, the deviation increases when the level of arch length is higher ($P < 0.05$). Therefore, the clinician should notice the deviation when using IOSs for the spaced cases or longer arch length. The discrepancy increases when scanning the posterior teeth. Excellent diagnosis paired with digital tools can improve the efficiency of treatment.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This study is grateful for the partial support of the Kaohsiung Medical University Hospital by KMUH108-8G04 and National Science and Technology Council by fund MOST111-2314-B-037-043-MY3.

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