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Reliabilty of recording occlusal contacts by using intraoral scanner and articulating paper - A prospective study

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ABSTRACT

Objective: The recording of occlusal contacts is a pivotal step in many dental procedures, yet the lack of a standardized method could introduce clinical errors. The aim of this study was to compare the occlusal contacts recorded using a intraoral scanner to the contacts recorded using articulating paper. As a secondary outcome, the subjective clinical assessment made using the two methods was compared between different observers.
Methods: Twenty-eight records were analysed for this study. Digital scan and intraoral photos of the coloured marks impressed by articulating paper were taken at the same time point for every patient. Using a standardized occlusal template, two operators recorded the number of occlusal contacts for every tooth provided by the two techniques. Then, 11 clinicians analysed the collected records and answered questions about the quality of the occlusions observed.
Results: The statistical analysis showed significant differences between the number of contacts recorded by digital scan and those recorded by the photographed articulation marks, except in the case of the upper central incisors and first premolars. The Kappa Fleiss showed slight and fair agreement between clinicians when judging the occlusions.
Conclusion: The occlusal contacts recorded using the intraoral scanner and those recorded with the articulating paper did not match, and overall the clinicians showed low agreement when rating the recorded data.
Clinical significance: Despite of the great clinical importance of occlusal contact there is a lack of a precise method for recording and collecting occlusal contacts.

1. Introduction

The predictable and accurate recording of occlusal contacts is fundamental in every phase of dental treatment, from the initial diagnosis to the finishing touches [1,2]. The recording of static and dynamic occlusal contacts is important for many branches of dentistry such as orthodontics, prosthodontics and restorative dentistry [1,3]. Despite the great importance of occlusal contacts, there are no objective criteria or a valid "gold standard" for their recording [4]. In fact, many different tools are used for recording, collecting and transferring occlusal information, but there is a lack of accurate quantitative measures for occlusal contacts [5]. This topic is the focus of debate in the literature, with many articles analysing different materials and methods used for recording occlusal contacts. Since there are no specific rules for the use of occlusal contact indicators, or any objective standards for assessing their results, clinicians should test every indicator before using them to achieve more reliable measures [6]. The methods conventionally used in clinical practice are articulating paper, impression waxes, bite wafer and shim-stock foils [7]. According to some authors, a simple transparent acetate sheet is also a good and reproducible method for recording marked occlusal contacts [3]. However, articulating paper is the most used diagnostic tool [8] and the subjective interpretation of articulating paper marks is the most common method used by clinicians to evaluate tooth contacts for occlusal treatment [9]. Unfortunately, the recording of occlusal contacts with articulating paper has some limitations: first of all patients have to bite several times to acquire full arch contacts; the

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bite sequence cannot be analysed and finally saliva can affects the results promoting the creation of false positives and false negatives [10]. Additionally, noticeable variations were found between the labelled size and real measured size for some of the currently available articulating papers [11,12]. Of course, the thickness of the marking materials affects the size of the mark and means that the clinician must select the most appropriate material in each case [13]. Moreover, a literature review by Sharma et al. reported that when used more than once some tools such as articulating papers revealed a different number of dental contacts [5], raising concerns about the predictability of this method.

The growing use of digital technology in dentistry offers the potential for improvement in the recording of occlusal contact. Intraoral scans present superior time-efficiency compared with conventional approaches and can accelerate the workflow if the clinician is properly trained [14–17]. The advantages also concern an improved patients' comfor and a faster and easier data processing and storage [18,19]. Furthermore, the contacts observed in partial digital scans for individual restorations and some element bridges were significantly more accurate than those taken with traditional physical casts and provided more objective and meaningful data [17]. Conversely, conventional impressions still appear to be the best solution for long-span restorations [20]. Therefore, some improvement in software accuracy is necessary to achieve greater reliability of the measurements [1]. The aim of this study was thus to compare occlusal recordings taken with articulating paper, and those taken with an intraoral scanner. Moreover, because occlusal recording is ultimately a diagnostic and treatment tool, the secondary outcome was the rate of agreement among clinicians in subjectively evaluating the occlusal contacts using either articulating paper or digital scan. The null hypothesis was that there is no difference between the occlusal contacts recorded using the two methods. For the secondary outcome, the null hypothesis was that no difference exists between the agreement based on articulating paper or on intraoral scans.

2. Materials and methods

This prospective study was approved by the Ethical Committee of the University of L'Aquila (protocol no 39873, ID 06/2020). The research was performed in accordance with the Declaration of Helsinki from 1975 and subsequent revisions and written informed consent was obtained from every subject before collecting data.

The participants were recruited from patients treated at the Orthodontic Clinic, Department of Biotechnological and Applied Sciences - University of L'Aquila.

Patients were considered eligible according to the following inclusion criteria:

- full permanent dentition, except for the third molars
- need for digital scans due to an orthodontic treatment with clear aligners
- normal mouth opening

Exclusion criteria were:

- anterior or posterior open-bite
- temporomandibular joint disorders
- missing teeth or previous orthodontic extractions

There were no restrictions for age, sex, or ethnicity.

The sample size estimation (G*Power version 3.1.9.2, Franz Faul, Universitat Kiel, Germany) revealed that to detect a large effect size [21] of 0.8 with a 5% first type error and a power of 0.95, using a paired signed rank Wilcoxon test, 24 subjects would be needed.

According to the aforementioned criteria, 24 subjects (16 females and 8 males, mean age 29,4 years) were enrolled in the study group. For each participant, digital scans and photographs of articulating paper marks were collected and analysed by two operators. Since, the digital scans and photographs of articulating paper marks of four subjects were repeated at two different time points, a total of 28 records were considered and analyzed.

2.1. Digital scan

The digital scan of the entire upper and lower dental arch were acquired by the same experienced operator (MT) using an intraoral scanner (CS3600 Carestream, Carestream Health, Inc., NY, USA) following the manufacturer's recommendations after positioning a soft lip retractor (OptraGate, Ivoclar Vivadent, Schaan, Liechtenstein) and drying the dental surfaces with an air blower: to acquire the digital impression of the upper arch, the intraoral scanner was first positioned as close as possible to the surface of the most distal erupted molar on the left side, with the intraoral scanner head angulated at 45° from the molar long axis, to frame both the occlusal surface and the palatal surface of the tooth. Then, the intraoral scanner was moved along the entire dental arch at the same distance and angulation toward the most distal erupted molar on the right side. At this point, the procedure was repeated with the intraoral scanner angulated at 45° to frame both the occlusal and buccal surface of the teeth, starting again from the left side. Then, the impression was completed by scanning all of the missing area and undercuts while checking for scanning errors. The same procedure was repeated for the lower arch, starting the scan from the right side. To record the occlusal relationship, the patient was asked to close their mouth in centric occlusion and instructed to keep their teeth in contact but without clenching: then, four digital recordings were taken – at the level of the left first molars, left canines, right canines, and right first molars – starting from the occlusal surface and moving the intraoral scanner head first cranially and then caudally, until the upper and lower scans were recognized by the software and properly matched. Finally, the matched digital models were checked for missing areas, artifacts or interpenetrations and the procedures were repeated if needed. The occlusal contacts were evaluated through a specific function of the intraoral scanner software, where the contacts are shown as a coloured map depicting the intensity of the contact from blue (light contact) to red (strong contact) (Fig. 1A).

2.2. Articulating paper

During the same appointment, the occlusal contacts were also recorded using a 8 μm articulating paper (8 μm Arti-Fol; Dr Jean Bausch GmbH & Co KG, Köln, Germany): the patient was seated in an upright position and instructed to close his/her mouth in natural centric occlusion, repeating the movement until the operator was sure that the patient was able to reproduce a correct intercuspation. At this point, the occlusal surface was dried with an air blower and two pieces of articulating paper, held by articulating paper forceps, were interposed between the dental arches on the left and right sides simultaneously, then the patient was asked to close his/her teeth three times in the previously instructed position. While keeping his/her mouth open to preserve the articulating marks, two occlusal photographs (D90 camera equipped with 105 mm lens, Nikon Corporation, Tokyo, Japan) of the upper and lower dentition were taken by the same experienced operator (xx) with a standardized technique using a lip retractor and a mirror (Fig. 1B).

2.3. Data collection

The occlusal photographs and the occlusal view of the dental contacts of the digital scans were analysed by two operators (xx and xx). Due to the difficulty in univocally defining coloured areas as "contact points", a template was prepared and used to standardize the measurements (Fig. 2A and Fig. 2B). The reliability of operators' measurements was assessed before data acquisition. The template was created considering the main anatomical areas of each dental element (incisal/

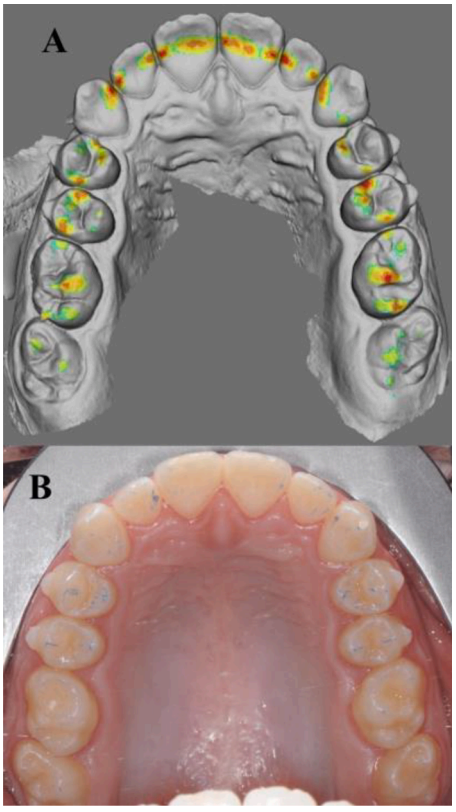

Fig. 1. Records of the upper arch of the same patient collected with two different instruments. A) Intraoral digital scansion. B) Intraoral photography with the occlusal contacts marked by the articulating paper.

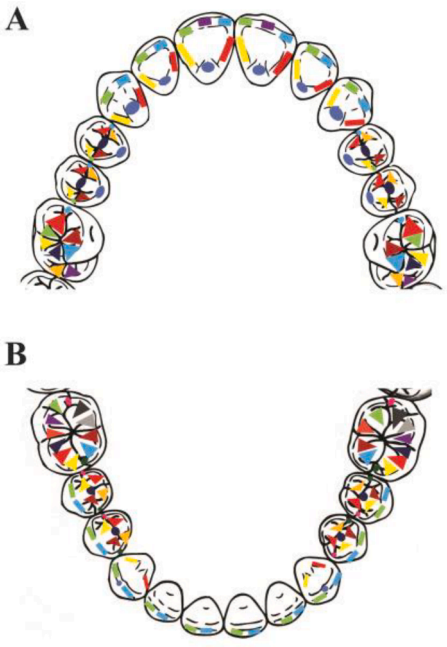

Fig. 2. Occlusal template used to perform the measurements. A) Upper occlusal template. B) Lower occlusal template.

occlusal surfaces, mesial and distal surfaces; cusp ridges, cingulum). If an anatomical area contained a mark or a coloured area, then a contact point was counted. Second and third molars were excluded from the analysis because of their position, which could have affected the precision of the measurements. The number of contacts for each upper and lower tooth, as evaluated independently from photographs and digital scans, was thus recorded, and stored for further analysis.

2.4. Subjective evaluation of occlusion

Finally, to evaluate if the clinical subjective evaluation of the occlusion differs when based on different acquisition methods, a questionnaire was prepared and submitted to trained clinicians. A PowerPoint (Microsoft Corporation, Redmond, Washington D.C., USA) document was prepared showing one image per slide, all with the same dimension. The images of the photographs of the articulating paper marks and of the occlusal contacts calculated by the intraoral scanner software of all 28 patients were inserted in the PowerPoint document in a random order without any identifier, so that the observers were not aware that the images belonged to the same patients or not.

Eleven well-trained dentists, with more than ten years of experience of both analogical and digital occlusal recording methods, were interviewed for the study. The clinicians were asked to answer some questions about the quality of the occlusion, basing their responses on the occlusal marks/color mapping they were observing on each image. The following questions were posed:

- Is the occlusion balanced?
- Are there any anterior or posterior occlusal inference contacts?
- Is the occlusion symmetrical or are there any left or right occlusal inference contacts?

2.5. Error of the method

To evaluate the error of the method and the reliability of the measurements the photographs and digital scans of 25 subjects, randomly selected using an online website (www.randomizer.org), were re-collected by the same two operators after 15 days. The rater reliability was tested through absolute agreement evaluated with a two-way random intra-class correlation test.

2.6. Statistical analysis

After collecting the data, a statistical analysis was performed to test the null hypothesis that there is no difference in the evaluation of the occlusal contacts detected using an intraoral scanner and articulating papers. Descriptive statistics for the count of occlusal contacts evaluated from digital scan and photographs of articulating paper marks were calculated. The Wilcoxon signed-rank test for paired samples was performed to evaluate the presence of differences between the number of occlusal contacts evaluated using the two methods. Those tests were performed using SPSS version 20.0 (Statistical Package for Social Science, IBM, Armonk, NY, USA).

Bland-Altman plots for the measurements of each tooth were derived calculating the difference between the two methods (articulating paper - intraoral scanner) and the mean of the two methods. Mean and Standard Deviation reference lines were also drawn.

Regarding the agreement in the subjective evaluation of the occlusion, the study was framed in the context of multiple raters with more than two possible ratings. Observers' agreement among 11 observers was calculated using the Fleiss Kappa [22] according to the diagnostic variables considered. In addition, z statistical tests were performed to assess or reject the hypothesis of no agreement. Those tests were worked out using the statistical software STATA version 17 (Stata Corp, College Station, TX, USA).

The type I error was set as 0.05 for all tests.

3. Results

The intra-rater agreement, assessed via the intraclass correlation

coefficient, was above 0.96 for contacts detected with articulating papers and 0.99 for contacts detected with the intraoral scanner.

Descriptive statistics are reported in Table 1.

Among the enrolled subjects: 17 patients had a class II molar relationship; 4 patients had a class II molar relationship, and 3 patients had a class III molar relationship.

The results of the Wilcoxon signed-rank test for paired samples are reported in Table 2. Most of the variables showed significant differences between digital scan and articulating paper, except for the upper first premolars and the upper central incisors.

Bland-Altman plots showed a trend for intraoral scans to provide a greater number of contacts relative to teeth that showed statistically significant differences in the Wilcoxon signed-rank test, while in non-significant teeth a random pattern of variation was observed (Fig. 3) (Supplementary file 1).

The variables' agreement, where relevant, is provided in the combined form to allow synthetic interpretation. The observers' agreement was explained following the ranges suggested by Landis and Koch [23] (Table 3) (Supplementary files 2–5).

The results were summarized using an agreement plot allowing comparisons between the methods used (Fig. 4).

4. Discussion

Both the primary and secondary null hypothesis were rejected. The primary hypothesis was refused because there were statistically significant differences for every tooth except for the upper central incisors and upper first premolars. While the secondary hypothesis was rejected because of the poor clinicians' agreement based on articulating paper or on digital scans.

In many dental procedures the operator needs to visualize and identify the occlusal contacts, and different instruments are available for this task [2,24]. The introduction of digital technologies, and in particular intraoral scanners, has provided the clinician a new instrument with which to define and study occlusal contacts [25]. Despite the widespread use of digital scan, there are limited and contradictory findings in the literature regarding their effectiveness in reproducing occlusal contacts [1,26], especially when a full-arch impression is taken [2,20,27]. The present study was thus aimed at comparing the occlusal contacts recorded in a full-arch digital impression acquired with an intraoral scanner to the current gold standard, i.e. articulating paper.

It was interesting to note how measurements taken on digital scan resulted in a higher number of contacts than those measured with articulating paper, except in the case of upper first premolars and the upper central incisors, both on the right and left side. It could be hypothesized that these exceptions could be explained by the simpler anatomy of the central incisors, where fewer contacts are always present, or by the position of the first premolar in the arch and the way the software elaborates the information provided by the intraoral scanner. The observed inconsistency between digital impression and articulating paper recordings is coherent with previously published data. Even if not

Table 2
Wilcoxon signed rank test for comparing occlusal contacts recorder with articulating paper and intraoral scanner.

Tooth (FDI number)	*Z*	*p*
16	−3.568**	0.001
15	−3.248**	0.004
14	0.776	0.735
13	−3.552**	0.001
12	−1.990*	0.047
11	−1461	0.203
21	−1535	0.125
22	−3.539**	<0.001
23	−3.775**	<0.001
24	−0.850	0.543
25	−2.055*	0.028
26	−3.188**	0.001
36	−2.402*	0.039
35	−3.102**	0.001
34	−3.714**	<0.001
33	−2.456**	0.01
32	−3.105**	0.002
31	−3.298**	0.001
41	−3.332**	0.001
42	−2.874**	0.003
43	−3.636**	<0.001
44	−3.463**	0.001
45	−2.284*	0.022
46	−3.153**	0.004

* Statistically significant for $p<0.05$;.
** Statistically significant for $p<0.01$.

Table 1
Descriptive statistcs for number of occlusal contacts recorded with either articulating paper or intraoral scanner.

Tooth (FDI number)	*Mean*		*Mediana*		*SD*	
	Articulating paper	*Intraoral scanner*	*Articulating paper*	*Intraoral scanner*	*Articulating paper*	*Intraoral scanner*
16	5.13	6.32	5	6	1.30	1.76
15	3.07	4.11	3	4	1.15	1.31
14	3.43	3.36	4	3	1.17	1.57
13	2.25	1.57	2	1.5	0.89	0.63
12	1.86	1.57	2	2	1.11	0.74
11	1.82	2.36	2	3	1.31	1.03
21	1.93	2.43	2	3	1.36	0.96
22	2.25	1.54	2	2	0.98	0.74
23	2.39	1.57	2	2	1.1	0.63
24	3.68	3.36	4	3	1.33	1.40
25	3.46	3.96	4	4	1.20	1.40
26	5.46	6.64	6	7	1.45	1.59
36	5.82	6.68	6	7	1.68	1.63
35	2.68	3.61	3	4	1.06	1.37
34	1.79	2.75	2	3	0.69	1.17
33	1.43	1.93	2	2	0.69	0.94
32	0.86	1.68	1	2	0.85	0.67
31	0.68	1.61	0.5	2	0.77	0.74
41	0.71	1.57	0.5	2	0.81	0.74
42	0.86	1.43	1	1.5	0.70	0.63
43	1.25	2.04	1	2	0.52	0.74
44	1.96	2.54	2	2.5	0.79	1.07
45	2.64	3.46	3	4	1.03	1.26
46	5	7.07	5	8	1.85	1.63

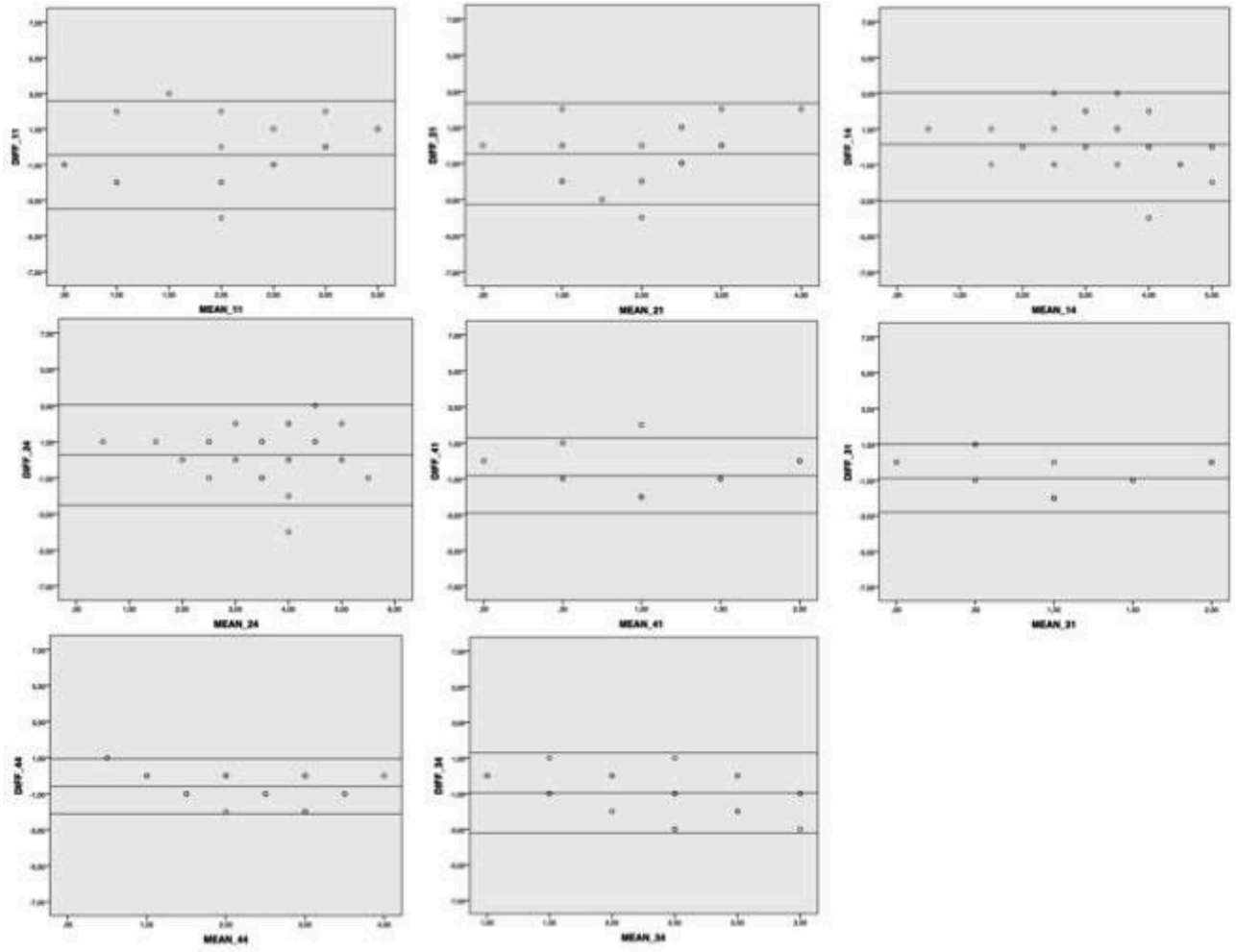

Fig. 3. Bland-Altman plots of central incisors and first premolars.

Table 3
Agreement table for clinicians' assessment ($n = 11$) of the occlusion based on the two different methods.

Main questions	*Main categories*	*Intraoral digital scanner*		*Articulating paper*	
		Fiest Kappa	*p value*	*Fiest Kappa*	*p value*
Is the occlusion balanced?	Yes No	0.32	<0.001**	0.06	0.012
Are there any anterior or posterior occlusal inference contacts?	None	0.15	<0.001**	0.01	0.326
	Yes	0.44	<0.001**	0.23	<0.001**
	No	0.22	<0.001**	0.05	0.024*
	Combined	0.25	<0.001**	0.07	<0.001**
Is the occlusion symmetrical or are there any left or right occlusal inference contacts?	None	0.23	<0.001**	0.06	0.007
	Right	0.29	<0.001**	0.11	<0.001**
	Left	0.13	<0.001**	0.13	<0.001**
	Combined	0.23	<0.001**	0.1	<0.001**

* statistically significant with p value <0.05;.
** statistically significant with p value <0.01.

unanimously proven, some authors have stated that contacts observed in the virtual environment are significantly more accurate than physical ones and provide more objective and meaningful data [17]. A systematic review by Fleming et al. aimed at evaluating the validity of digital models by assessing agreement with measurements on stone casts showed that digital models offer a high degree of validity when compared to direct measurement on stone casts; the differences between the approaches are probably clinically acceptable [28,29]. Despite this shortcoming and the alleged advantages of the digital method, articulating paper is still the method most used by clinical dentists due to its low cost and simple application [9]. Notwithstanding, it was shown that the visual inspection of articulating paper markings is a poorly effective method for determining relative contacts and occlusal force levels [9]. This was confirmed by the evaluation of observers' agreement, which was lower for the contacts taken with articulating paper than for those taken with the intraoral scanner. Even though there was very low agreement for both the collecting methods, the results of the present study suggest that occlusal contacts taken with a intraoral scanner could make clinical judgment easier and more predictable. The results of our study are consistent with some of the existing literature: a systematic review by Velasquez et al. concluded that digital occlusal analysis is more objective than traditional occlusal analysis in most interventions [30]. Nevertheless, the digital system seems to be less accurate than some authors reported: in fact, while single quadrant scan can reproduce the most accurate occlusal representation, the full arch impression is not as accurate [2,31]. This could partly explain the differences between contacts recorded with articulating papers and those recorded with the intraoral scanner. It is also important to note that our study differed from previous studies because it was one of the few where intraoral scans were taken. In fact, there are many studies that have reported the differences between stone casts and digital scans of stone casts, and some of them suggested that a way to avoid sources of errors linked to the process of scanning a stone cast would be to use an intraoral scanner directly in the mouth of the patient [32,33]. Moreover, even if digital

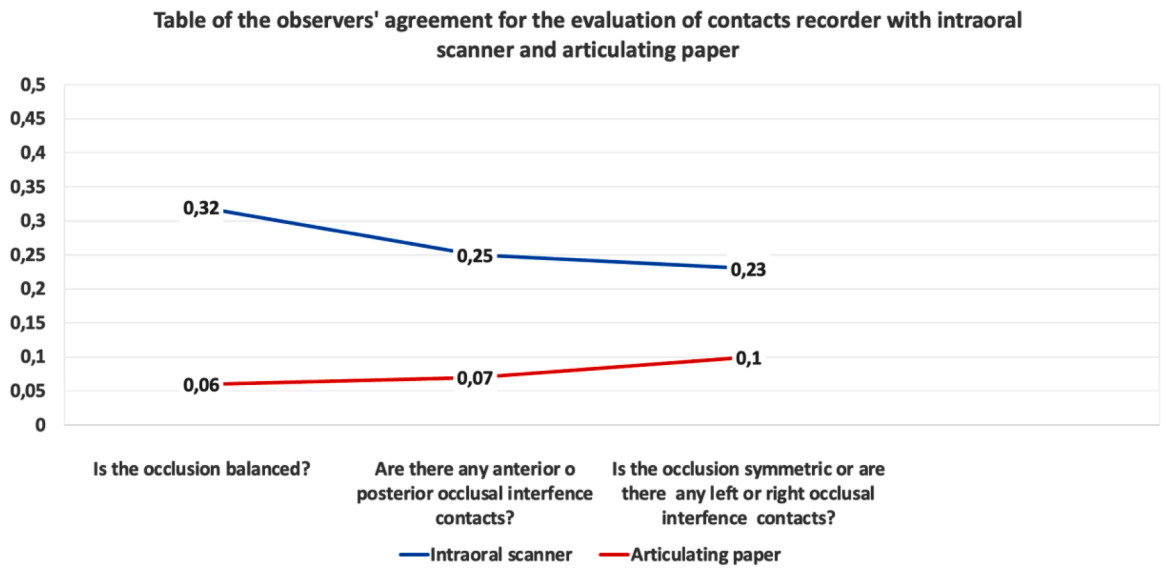

Fig. 4. Representation of the observers' agreement.

models are a good alternative to plaster models, the available evidence is of variable quality [29].

The results of the first part of the study were confirmed by the results on observers' agreement. It was clear that the degree of agreement was very low, showing that from a clinical point of view the information provided by both the articulating paper and the intraoral scanner is difficult to interpret and does not overlap. This is a very important result, given that these two methods are those most commonly used by clinicians to make a diagnosis and to take therapeutic decisions in an attempt to provide better occlusal stability. Furthermore, the lowest observers' agreement was obtained when the clinicians were asked if they would intervene to modify the occlusal contacts of some teeth to achieve a more balanced occlusion (Fig. 3). A more in-depth analysis of the agreement related to questions with multiple categories of answer and looking at the single answers rather than the combined results indicated that detecting the presence of anterior occlusal inference contacts is more predictable than detecting posterior prematurities.

In summary, there are different techniques available for recording occlusal contacts, each with its own limitations. The decision to use any of these techniques depends upon the clinical situation, the clinician's preference and expertise, economic considerations, and the patient's and operator's comfort [5]. Nevertheless, there is very low observers' agreement regarding the contacts collected with both the articulating paper and the intraoral scanner, suggesting that even if these are the most widely used methods for collecting occlusal contacts, their interpretation is extremely subjective.

The untold truth, however, is that a 100% accurate and precise method to reproduce dental contacts is still lacking and a certain degree of uncertainty is always present. Even articulating paper, which is considered the gold standard, is not perfectly accurate [6]. Moreover, the size of articulating paper marks is not an accurate indicator for the selection of tooth contacts for occlusal adjustment treatment [9,12]. In fact, the intensity of the markings obtained with articulating papers is not a reliable criterion for assessing the strength of the contacts as the interpretation is subjective [34]. Even other direct instruments for evaluating dental contacts, such as pressure sensors or the T-Scan, are never completely accurate because even the thinnest medium that is interposed between the opposing dental arches alters the quality and quantity of occlusal contacts because of their thickness (100 μm for the T-Scan). For these reasons, in our study, an 8 μm articulating paper was considered the gold standard for collecting occlusal records because its thickness should not interfere with the recording of occlusal contacts [35]. Precisely quantifying the occlusal contacts is not a trivial task. Indeed, articulating paper can produce smears that could hinder the interpretation of the marks, and digital scan reproduce the contacts as coloured areas with each color representing a different contact's intensity. Therefore, in order to standardize the quantification procedure, it was decided to apply the template reported in Fig. 2. This helped achieve very high agreement between the measurements, representing an advantage compared to a previous similar study where the absence of a template resulted in much lower rater agreement [35]. On the other hand, it introduced a certain amount of data synthesis, and this could be considered a limitation of the present study. Another limitation was the absence of a validation method of the actual dental contacts: none of the used techniques has been scientifically proven to be an "ideal" method to analyze the occlusion [10]. In fact, even if the articulating paper is clinically considered the gold standard a method for the exact quantification of real dental contacts does not yet exist.

5. Conclusions

The evaluation of occlusal contacts in adult patients with complete dentition was inconsistent between digital scan and articulating paper, except for the upper left and right central incisors and the upper left and right first premolars. Overall, a higher number of occlusal contacts was measured on digital scan, compared to articulating paper. Finally, the agreement between clinicians in the evaluation of the two methods was slight for the articulating paper and fair for digital scan.

CRediT authorship contribution statement

Rosa Esposito: Writing – original draft, Visualization, Resources, Methodology, Investigation. **Francesco Masedu:** Methodology, Formal analysis. **Marco Cicciù:** Writing – review & editing. **Michele Tepedino:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Martina Denaro:** Investigation. **Domenico Ciavarella:** Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2024.104872.

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