Optimal Use of Physical Centric Relation Records for Digital Workflows

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ABSTRACT

Correctly articulated dental casts are essential for certain dental treatment. Articulation can be traditional: using a physical articulator; digital: using a physical articulator followed by 3D scanning, or virtual: using 3D scanning and software to articulate scans without initial physical articulation. This study compared the precision of traditional articulation, using physical centric relation records and an articulator and virtually, by digitally aligning scans of the casts and record. Articulated casts and centric relation records were obtained. 12 record pairs were recorded from the articulated casts. Virtual method: all records were scanned, unclamped, in a custom laboratory scanner. The casts were aligned to each scanned record to create virtual articulations. Traditional method: each record was used to physically articulate the casts. Each articulation was recorded using an intraoral scanner. The mean inter-arch separation between three key-points on each cast-pair were used to determine differences in occlusal separation in three anatomical directions, and precision of methods. Traditional articulations: standard deviations in key-point distance never exceeded 0.102mm. The virtual equivalent was 0.059mm. Statistically significant differences ($p<0.05$) between all anteroposterior separation distances were found between the methods, and in three of six lateral/vertical separations. Virtual articulation was significantly more precise than traditional articulation.

INTRODUCTION

Centric relation (CR) is defined as "a maxillomandibular relationship, independent of tooth contact, in which the condyles articulate in the anterior-superior position against the posterior slopes of the articular eminence".[1]

Centric relation records are an important facet of diagnosis and rehabilitative dental treatment, aiding the correct orientation of the upper and lower study casts in CR for planning occlusal reorganisation therapy. Centric relation records can be used to articulate dental casts traditionally: by using a physical articulator, or virtually: by 3D scanning the records and aligning the scanned casts to these. However, encouraged by scanner manufacturer protocols, the most common way for a dental laboratory to utilize traditional centric relation registrations in a digital workflow is to physically articulate the dental casts first, and then scan the physically articulated set-up.

In this paper we present and investigate the precision of a "hybrid" workflow, which uses the centric relation records, but omits the physical articulation, unlike most current digital workflows. This investigation therefore uses the term "traditional" when referring to models being articulated using a physical articulator, even if this is prior to scanning, and therefore part of a digital workflow. The term "virtual articulation" is reserved for scenarios where a physical articulator has not been used at any stage.

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Both traditional and virtual articulation methods see the dentist record the patient's centric relation, before the records, along with impressions or dental casts, are passed on to the technician to be articulated. The technician may then choose to articulate the case using a physical articulator, or use a range of digital methods by which to digitally reproduce the articulation from either the centric relation records directly [virtually articulation] or from the traditional articulator. Since clinically recording centric relation is time consuming and challenging, the clinician is unlikely to take multiple centric relation records of a patient, to ensure precision, despite this being the biggest factor in correctly reproducing the patients' occlusal relationship.[2] Further, the process of physically articulating dental casts can be technique sensitive and at risk of poor reproducibility.[3–8] Traditional articulation methods have been reported to have low precision, resulting in occlusal adjustments being necessary in most cases.[9] Traditional methods are also time consuming for the dental technician, further reducing the likelihood of multiple articulations being done for the sake of best precision. As a result - that the method used to articulate the patient's dental casts is precise is essential.

Few dentists are equipped to virtually record the patient's centric relation, due the high cost of intraoral 3D scanners, despite much of contemporary treatment being digital during the laboratory stage: CAD/CAM crowns being just one example. As a result, technicians commonly need to produce digitised articulations using centric relation records to be able to produce the requested dental work. This may involve scanning casts individually, and then mounted on the articulator, before aligning all scans.[10] Scanning articulated casts is problematic, requiring rigid clamping, and either a large scan-space to fit the articulator, or more commonly, custom locking plates and complex mechanisms to fit the articulated casts into the dental scanner. This process introduces all errors produced in traditional articulation, as well as the risk of movement of the dental casts during scanning into the resulting digital articulation. (See [11] for an overview over the most common current methods of digital articulation.) An alternative technique involves scanning casts individually, and independently scanning the interocclusal record;[10] the casts are then digitally aligned to the scan of the occlusal record. Conventionally, this technique requires that all records are stabilised and clamped into position, which introduces distortion.[12]

By using a clamp-less, custom made scanner,[13] the current study aimed to investigate the precision of virtual versus traditional articulation, assuming little, or no distortion to the occlusal records during scanning. If scanning the centric relation records in isolation, before virtually articulating the casts were shown to be true and precise, and since the majority of dentists do not have access to intraoral scanners, yet many laboratories have model scanners, it would be useful to harness a hybrid, 'semi-digital' workflow; where the clinician follows the conventional method of taking centric relation records, before the technician scans the records and virtually articulates the dental cast scans against these, without needing to use a physical articulator. Therefore, identifying the precision of the two methods under investigation could allow insight into whether alternative articulation methods, such as the hybrid method presented, may be of value to the field.

Traditionally, high levels of surface detail captured using centric relation records may preclude the records from seating fully on the dental casts.[14] This has led to the clinical advice to trim the bite registrations significantly – a technique sensitive procedure. Virtual articulation, where the centric relation records are scanned in isolation, may offer a method of articulating dental casts more accurately. This is because the digital alignment of scanned centric relation records (without fixing the records onto the cast before scanning) differs from traditional articulation in that digital alignment may benefit from maximising the available information (i.e. having a larger interocclusal record that records the embrasures and tooth bulbosities). Traditional articulation tolerates these features poorly as the record will often fail to fully seat on casts if gross undercuts or narrow embrasures are incorporated into the interocclusal record; these can be difficult to fully remove while retaining sufficient positive 'fit' of the record on the casts. Virtual articulation methods alleviate this issue, as alignment disregards any penetrating meshes. This also results in plaster pearls or other minor, but potentially clinically relevant, imperfections on the physical cast not negatively affecting the virtual articulation in the same way it might affect the traditional method.

While the virtual methods may forgo some of the error-inducing aspects of the traditional articulation methods as listed above, virtual methods rely on repeatable and accurate digital alignments. Previous work shows that obtaining and assessing clinically correct digital alignment is a challenge.[15] As such, both methods under investigation contain their own challenges which impact the precision of articulation.

This study investigated the precision of two methods of articulating casts using centric relation records: a) traditional articulation using vinyl polysiloxane bite registration material and b) virtual articulation using digital alignment of scanned, unclamped, centric relation records and the scanned dental casts. Unlike other digital methods which rely on physical articulation, and may include inherent errors introduced at this stage when digitised, we ensure that none of the error potentially introduced during the laboursome process of using a traditional articulator is accidentally included in the virtual workflow by not using a physical articulator at any point. This method would not require any change to the clinicians' workflow. An intraoral scanner was used to record the traditional articulation to enable a comparison between the two methods.

NULL HYPOTHESES

1. There is no statistically significant difference in the precision of traditional articulation and virtual articulation methods using vinyl polysiloxane centric relation records, measured as the variation in arch separation at three locations

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2. There is no statistically significant difference in the mean arch separation, measured at three locations, between traditional articulation and virtual articulation methods using vinyl polysiloxane centric relation records

METHOD

IMPRESSION AND CENTRIC RELATION RECORDS

A set of traditional upper and lower fully dentate impressions were taken using a dual phase polyvinylsiloxane (Affinis heavy and medium body, Coltene Group Ltd) in rigid stock trays. The impressions were cast in type III stone. The respective casts were verified clinically to assess for errors in critical areas involved in the occlusion. Centric relation records were taken using an anterior jig (Duralay, Reliance, IL, USA) according to standard clinical technique with an incisal separation of approximately 3mm, and using two posterior vinyl polysiloxane (Blumousse, Parkell Inc.) registrations; these extended from the first molar to the canine teeth bilaterally. The casts were articulated on a semi-adjustable articulator (Denar® Mark II, WhipMix, KY, USA) using average values for the position of the upper cast and the settings of the condylar housings. The centric relation record was used to mount the lower cast, and the articulator pin remained set at the height of these records to maintain the incisal separation.

Next, 12 centric relation records were taken on the articulated casts, using vinyl polysiloxane. All records were assessed for drag and over-extension into undercuts. The records were all trimmed with a scalpel to remove fine detail, in accordance with good clinical practice.

VIRTUAL ARTICULATION

The unarticulated upper and lower dental casts were scanned using a custom lab scanner (Leeds Digital Dentistry). Each pair of centric relation records were scanned, unclamped, using the same scanner *(Figure 1)*.

To virtually align the scans in the correct intermaxillary relationship, the upper and lower jaw and each of the 12 pairs of the centric relation records were aligned. The two records were

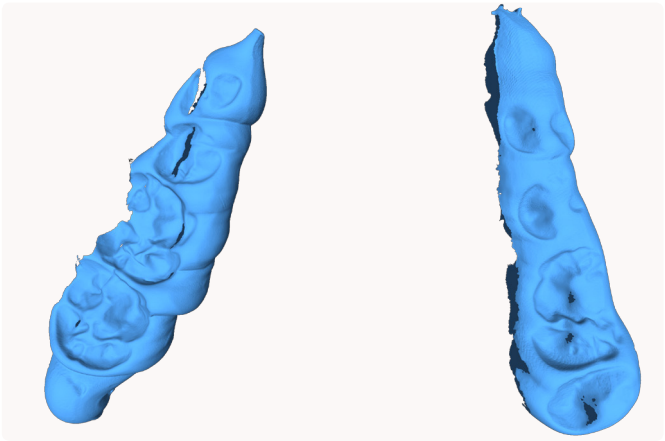

Figure 1: Centric relation records

individually aligned to the upper cast, using global alignment in WearCompare,[13] before the alignment was refined using Meshlab.[16] This alignment process was then repeated, but this time aligning the lower cast to the two repositioned centric relation records, bringing all four meshes into "articulation". The alignment transformation was saved. This was repeated for all 12 pairs of scanned centric relation records *(Figure 2)*.

Measurement of these alignments proceeded as described later.

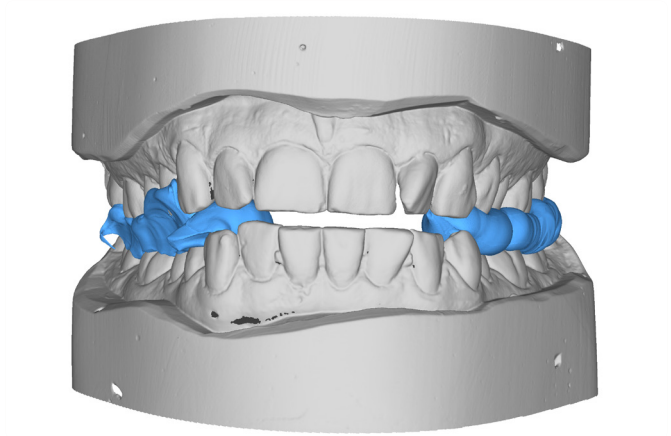

Figure 2: The cast scans having been articulated by aligning to the scans of the left and the right centric relation records (Virtual group).

TRADITIONAL ARTICULATION

Following scanning, all twelve centric relation record pairs were used to physically re-articulate the lower cast on the articulator. This process involved removing the mounting plaster from the previously articulated lower model, and the use of a new mixture of low expansion mounting plaster to re-articulate the model using a different CR record. Each cast was assessed visually for correct seating into the centric relation record. A facebow record was not utilised and the upper cast remained mounted throughout, with the articulator pin unmoved and set at the original incisal separation. The protrusive, immediate side shift and progressive side shift adjustments remained unchanged at factory settings throughout *(Figure 3)*.

In order to measure the traditional articulations, it was necessary to digitise each dataset. To achieve this, each set of articulations were scanned with two optical buccal bite records whilst mounted on the articulator using an intraoral scanner; Omnicam (Ortho 1.1.2). The full arch casts were also scanned with the Omnicam once, and this same set of scans was used during each articulation, to minimise confounding variable *(Figure 4)*.

The precision of this Omnicam method for measuring traditional articulations was investigated by scanning two buccal bite records on the same articulated casts five times without opening the casts between scans.

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Figure 3: Physical articulation (Traditional group only).

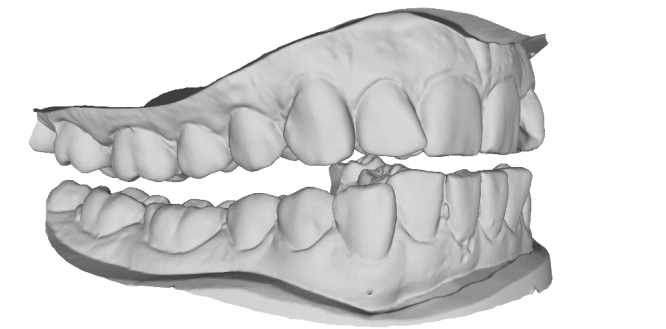

Figure 4: Articulated scans produced by the Omnicam, based upon physical articulation (Traditional group only).

The CEREC Ortho software maintains the position of the lower arch and moves only the upper arch, based on the buccal bite scans. Therefore, all lower scans were aligned to the cast scanned in the custom Leeds scanner and the transformation matrix for each alignment was applied to the corresponding upper arch. This brought scan-pairs into the same alignment, whilst preserving idiosyncratic differences in the individual occlusions.

MEASUREMENT OF ALL ARTICULATION METHODS

Three pairs of vertex points were identified across the upper and lower arch on the scans produced by the laboratory scanner in Meshlab, located on UR1,LR1; UR7,LR7 and UL7, LL7. The coordinate of each of the three points per arch, were recorded using custom software (Leeds Digital Dentistry), as outlined in [17]. The identical key points were then identified on all twelve scan pairs produced by the Omnicam (the "Traditional" articulation), as outlined in [17]. The "Virtual" arm of the study (using the clamp-less scanner) consisted of one set of casts with twelve different transformation matrices. Thus, the new location of the originally identified key points were identified by vertex-ID and recorded.

The X, Y and Z values for the displacement between upper and lower key point pairs were assessed separately, for each pair of key points. All casts were oriented such that Z represented the anteroposterior direction, X was lateral, and Y was superior-inferior.

The standard deviation was used as a proxy for precision, whilst a comparison of mean values indicated whether the methods produced a different occlusal result in the three anatomical directions.

STATISTICAL ANALYSES

The precision of using the Omnicam bite scan to record the physical articulation group, was reported using the standard deviations for the directions in X, Y and Z between upper and lower key points, for the three key point pairs (Anterior, Left, Right). This initial assessment used the five repeated buccal bite scans from a single instance of the articulated casts (where the articulator had not been moved in between each scan).

Next, differences in the physical and virtual methods were assessed, using the 12 different polyvinylsiloxane centric relation records as follows.

The mean separation between upper and lower key points in the directions X, Y and Z were compared for the Traditional and Virtual groups using Students paired t-test. Beforehand, homogeneity of variance for the differences between each group was confirmed using Shapiro-Wilk. Significance was set at $p<0.05$.

The precision of the articulation was assessed using Levene's Test to compare the variances in the separation between upper and lower key points in the directions X, Y and Z. Significance was set at $p<0.05$.

RESULTS

The Omnicam precision experiment produced standard deviations in key point distance which never exceeded 0.032mm laterally (X), 0.033mm vertically (Y) and 0.03mm anteroposteriorly (Z). See Table 1 for all findings.

For the traditionally articulated casts, standard deviations in key point distance never exceeded 0.076mm laterally (X), 0.102mm vertically (Y) and 0.073mm anteroposteriorly (Z). The virtual equivalent was 0.027mm laterally (x), 0.059mm vertically (y) and 0.024mm anteroposteriorly. Statistically significant differences ($p<0.05$) between mean values for Traditional and Virtual articulations were seen in all anteroposterior separations, and three of the six lateral and vertical separations. Statistically significant differences in variance (precision) were seen in all anteroposterior measurements, and all lateral measurements. See Figure 5 and Table 2 for all results.

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Table 1. Precision of the Omnicam method for assessing the Traditional arm of the trial, across three axes and across the three key points.

Precision of Omnicam for Measuring Traditional Articulation (mean mm) (± standard deviation)			
	X	Y	Z
Anterior	0.051 (±0.032)	1.802 (±0.033)	0.289 (±0.012)
Right	-2.651 (±0.022)	2.192 (±0.030)	2.117 (±0.030)
Left	-0.672 (±0.022)	2.782 (±0.015)	7.135 (±0.013)

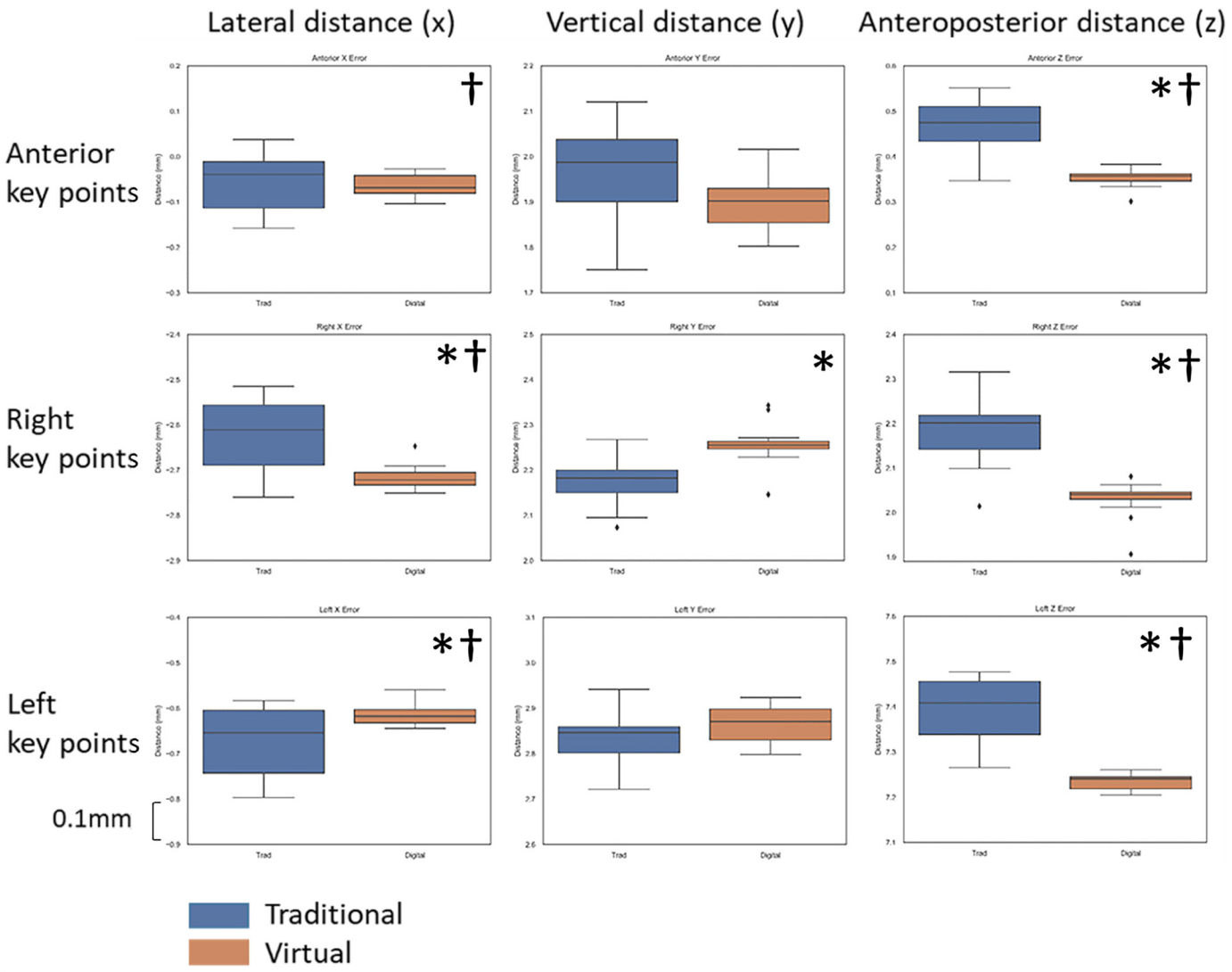

Figure 5: Variation in key point distance for all three key points across the traditional group (blue) and the virtual group (orange). Y axis scale = 0.1mm per unit. * denotes a statistically significant difference ($p < 0.05$). † denotes a significant difference in variance (precision).

DISCUSSION

This study investigated the precision of traditional and virtual articulation using centric relation records.

The first null hypothesis posed no statistically significant difference in precision between the articulation methods. In this experiment, the precision was defined as the standard deviation of the variation in upper and lower key point separation in the anteroposterior (Z), lateral (X) and vertical (Y) directions. Significant differences in anteroposterior and lateral directions, for all key points pairs across the two methods, lead us to reject this hypothesis.

The second null hypothesis stated that there would be no statistically significant difference in articulations produced by both methods. The articulations were defined in terms of upper/lower key point separations in the three anatomical directions

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Table 2. Key point distance for both experiments in mm (± standard deviation)

Key point distances for the two methods (mean mm) (±standard deviation)						
	Trad X	Virtual X	Trad Y	Virtual Y	Trad Z	Virtual Z
Anterior	-0.056 (±0.067)	-0.058 (±0.028)	1.972 (±0.102)	1.907 (±0.059)	0.462 (±0.063)	0.353 (±0.017)
Right	-2.617 (±0.076)	-2.720 (±0.019)	2.171 (±0.053)	2.270 (±0.034)	2.179 (±0.073)	2.038 (±0.023)
Left	-0.670 (±0.071)	-0.617 (±0.018)	2.841 (±0.057)	2.872 (±0.034)	7.396 (±0.068)	7.228 (±0.024)

noted above. In six of the nine test cases, a different mean value was recorded. In particular, all anteroposterior means differed significantly between Traditional and Virtual groups, with digital consistently producing smaller values. Therefore, the second null hypothesis is also rejected.

In considering the Traditional measurements using the Omnicam, it is worth noting that the precision measurements (standard deviations) for the main experiment were consistently double the values found in the preliminary experiment. Our preliminary experiment (which investigated the precision of the Omnicam in measuring the same articulation multiple times), resulted in standard deviations of around 0.03mm in each of X, Y and Z. These values agree well with previously published results,[18] although in the current experiment the precision is slightly poorer. This may be due to the increased separation between the teeth when recording centric relation registrations vs recording intercuspal position. The intraoral scanner collects less data per-frame in the former case, because of the increased gap between the upper and lower teeth, and therefore has slightly poorer data with which to 'glue' the upper and lower arches together. Overall, while some of the variance in the Traditional articulations can be explained by variance in our measurement method, an equal amount of the variation cannot, and must be attributed to genuine differences in the physical articulation of the casts.

Note also, that these centric relation records were all recorded on the casts, not in the mouth. This was to reduce the variation in mandibular position, which might confound the results. However, in general, in vivo records will not necessarily seat as perfectly on *in vitro* casts, because of variations in the level of detail recorded. Thus, in our experiment the Traditional arm is likely to perform better than would be the case in clinical practice.

The centric relation records were trimmed of extraneous detail before use, as is often recommended clinically. This aids the full seating of such records on stone casts. However, this process would not be needed for the virtual method (because 3D meshes can pass through each other), and it could be argued that such trimming should be avoided, since useful detail is lost. Therefore, our results may be an under-estimate of the precision of the Virtual method.

The clinical implications of this experiment point towards an improved method of articulating dental casts in centric relation, which uses entirely familiar and available chairside techniques (in contrast to the low availability of intraoral scanners). It requires that the dental laboratory has sufficient cast scanning capabilities, but this tends to be more common in laboratories than in dental practices.

Further, this 'hybrid' of traditional chairside techniques coupled with modern high-resolution digital techniques may offer the best of both approaches. It is cost effective, simple, and may offer a better quality full-arch articulation than that produced by an intra-oral scanner alone (as seen here with Omnicam).

We cannot assess the trueness in this experiment, but high precision is desirable in any clinical technique. In particular, the anteroposterior precision of repeated centric relation records using our Virtual method never exceeded 0.025mm, while the Traditional articulations were consistently more than 0.060mm. It may also be worth noting that the precision of the five identical Omnicam repeats produced articulations less precise than the precision of the 12 different articulations produced using the digital method in the main experiment. The precision with which the Traditional articulations were recorded may have been improved by using a more recent intraoral scanner. The use of an extra-oral scanner (NextEngine, CA, USA) to digitise the articulations was investigated, but the results proved less reliable than the Omnicam scanner and were therefore not included in this manuscript. Trueness could be investigated, perhaps, by 3D printing a Michigan Splint and fitting this onto the articulated casts to test the number of occluding units on the splint. This would give a clinically relevant indication of the occlusal fit of both methods under investigation. This falls beyond the scope of the current experiment but is suggested as worthy of further investigation in the future.

It is likely that digitizing the centric relation records and mounting the casts virtually will confer a clinically detectable benefit over scanning a physical version of the articulated casts (as is currently the most common practice). Further work should be undertaken to compare this method with intraoral scanners, particularly in the use case of the centric relation record as opposed to an intercuspal record.

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CONCLUSION

The precision of a virtual method for articulating dental casts using a traditional centric relation registration was compared to the traditional plaster mounting on an articulator. A significantly improved precision in articulation was noted for the Virtual group. This method does not require the clinician to modify their chairside technique or invest in expensive chairside scanning equipment.

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