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ORIGINAL ARTICLE

Accuracy of transfer of bite recording to simulated prosthetic reconstructions

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Abstract
Objectives A key aspect of complex restorative therapy is reconstruction of a new three-dimensional jaw relation. The objective of this study was to test the hypotheses that the initially recorded jaw relation would deviate substantially from the jaw position of the prosthetic reconstruction and that activity ratios of the jaw muscles would be significantly different for each of these jaw positions.
Materials and methods In 41 healthy subjects, 41 examiners incorporated intraoral occlusal devices fabricated with all the technical details and procedures commonly used during prosthetic reconstructions. The jaw positions in centric relation with the incorporated occlusal devices were telemetrically measured in the condylar, first molar and incisal regions, relative to intercuspation. Electromyographic (EMG) activity of the temporalis and masseter muscles was recorded, and activity ratios were calculated for homonymous and heteronymous muscles.
Results The recorded jaw relation differed significantly ($p < 0.001$) from the jaw position reconstructed with the intraoral occlusal devices. The initially recorded jaw relation was reproduced with the intraoral occlusal device with spatial accuracy of approximately 0.3 mm in the condylar, molar and incisal regions. The EMG ratios between centric relations and the reconstructed positions were significantly different ($p < 0.05$) for the temporal muscle and the temporalis/masseter ratio.
Conclusions The findings revealed that three-dimensional jaw-relation recording may be reproduced in a simulated prosthetic reconstruction within the accuracy reported for replicate intraoral bite recordings.
Clinical relevance Centric relation recordings may be reproduced in a prosthetic reconstruction with the spatial accuracy of 0.3 mm.

Keywords Centric relation accuracy · Prosthetic reconstruction · Intercuspation · Electromyography · Jaw relation reliability

Introduction

An important aspect of complex restorative therapy is reconstruction of the three-dimensional jaw position determined by the so-called centric relation of the condyles and a specific vertical opening at the point of the incisors. This position usually differs to some extent from the jaw relation determined by the patient's previous intercuspation [1–4]. It is well known, however, that this artificially established relationship between the maxilla and mandible, recorded by use of a variety of manipulation techniques, is adapted too well by the neuromuscular system and the tissues involved. Reproducibility of a recorded centric relation is an essential prerequisite in prosthetic dentistry because bite recording and intraoral or extraoral occlusal adjustments after incorporation of reconstructions need a unique, reproducible jaw-guiding technique to ensure evenly distributed occlusal contacts.

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Several studies [5–12] have investigated the reproducibility of different recording techniques which are supposed to provide a centric relation of the condyles in their fossae. The reproducibility was fair to good, but no single technique was able to reconstruct the genuine jaw relation. Moreover, the various techniques resulted in jaw relations different from intercuspation [12].

The accuracy with which an initially recorded centric relation, i.e. the determined three-dimensional jaw position, can be reproduced by a specific prosthetic reconstruction is unknown (in the following discussion the three-dimensional jaw position in centric relation will be denoted “centric jaw relation”).

Previous studies have investigated changes of electrical activity, in different jaw positions, provoked by intraoral splints or variable occlusal support [13–17], but an unsolved question is: to what extent are neuromuscular reactions of the masticatory muscles induced when adapting to the finally reconstructed jaw position? In an attempt to answer this question, we performed prosthetic procedures with healthy students using intraoral acrylic devices (to simulate prosthetic reconstructions) and compared the initially recorded centric jaw relation with that of the incorporated device and genuine intercuspation. The complex technical manufacturing procedures and the intraoral and/or extraoral corrections during adjustment of occlusion are sources of imperfection which may affect the accuracy of the initially recorded three-dimensional jaw relation [18]. For measurement of possible neuromuscular reactions, in particular variation of the electrical activity of the muscles induced by the procedural changes of the vertical and sagittal jaw relations [19, 20], the electromyographic (EMG) activity of the masseter and temporalis muscles was recorded. We hypothesised that all the jaw positions compared would deviate significantly from each other and that, as a neuromuscular consequence, the electrical activity ratios between homonymous and heteronymous masticatory muscles would change because of slightly different left and right jaw gaps and/or anteroposterior jaw displacement in each of the positions investigated.

Materials and methods

Subjects

Forty-one healthy students, 31 females and 10 males (average age 24±2 years), were enrolled in the study. Exclusion criterion was painful temporomandibular disorders assessed by the Research Diagnostic Criteria for Temporomandibular Disorders [21]. Except for third molars, all subjects had full dentition. The study was approved by the Ethics Committee of the University Medical Centre, Heidelberg (# S-130/2010). All subjects gave their written informed consent to participation in the study.

Experimental procedure

The following sections provide a chronological overview of the experimental procedure. The complete production process was performed by undergraduate students under the supervision of two experienced dentists.

Jaw relation recordings

Dental impressions were taken by use of alginate (Xantalgin® select, Heraeus Kulzer GmbH, Hanau, Germany), and stone gypsum (Octa Stone, Heraeus Kulzer GmbH, Hanau, Germany) was poured in. The maxillary casts of the subjects were transferred to an articulator (SAM 2PX, SAM® Präzisionstechnik GmbH, München, Germany) by use of an arbitrary facebow (Axioquick anatomic transferbow, SAM® Präzisionstechnik GmbH, München, Germany), and mandibular casts were mounted in intercuspation. The casts were separated in the incisal region by approximately 5 to 6 mm. An acrylic (Lightplast, Dreve Dentamid GmbH, Unna, Germany) wafer with a small flat frontal plane was fabricated on the upper cast so that the posterior regions were free from tooth contacts. The plateau of the wafer was fed with a small piece of bite wax (Alu Wax Denture, American Dental Systems GmbH, Vaterstetten, Germany) to mark the positions of the lower front teeth on the plateau and to avoid their displacement by sliding during centric relation recording, and the posterior parts were lined with pattern resin (GC Pattern Resin LS, GC Germany GmbH, Bad Homburg, Germany) in four discrete regions of the canine and molar zones, bilaterally (Fig. 1). Recording of the centric relation (BR) was accomplished as follows: (a) the left hand was used to fix the acrylic wafer on the maxilla and (b) the examiner gently guided the subject’s mandible to the posterior position by use of the “Lauritzen” technique [22].

This procedure was supplemented by the instruction to position the tongue tip at the posterior border of the palate.

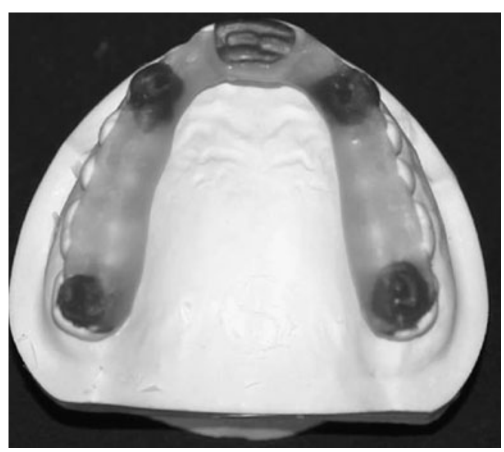

Fig. 1 Acrylic wafer for bite recording, relined with pattern resin in the canine and molar regions

This position was held by the subjects until the pattern resin cured. When recording was complete, the frontal plateau was reduced and the lower casts were remounted in the articulator in accordance with the recording of the centric relation.

Fabrication and incorporation of occlusal devices simulating prosthetic reconstruction

Acrylic (Palapress®, Heraeus Kulzer GmbH, Hanau, Germany) occlusal devices with anterior guidance and cusps and fossae profiles on their posterior parts were fabricated on the upper casts by students following all appropriate technical dental laboratory procedures. The devices were inserted and adjusted in the manner commonly used for prosthetic reconstructions. The following criteria had to be met: (a) fitting without any movement or jiggling and (b) holding of 10-μm occlusion foil (Shimstock Metal Foil, American Dental Systems GmbH, Vaterstetten, Germany) between all posterior teeth with slight bite force.

When both criteria were fulfilled, an experienced dentist monitored the splints, and, if necessary, suggested modifications. The lower jaw position was then stabilised on the occlusal device by use of the pattern resin (GC Pattern Resin LS, GC Germany GmbH, Bad Homburg, Germany) in four discrete areas in the premolar and molar regions, bilaterally (Fig. 2).

Jaw relation measurement

Three different jaw positions, i.e. maximum intercuspation (IC), jaw relation with inserted bite recording (BR) and jaw relation with inserted occlusal device (OD), were recorded by use of a modified ultrasonic telemetric system (WinJaw, Zebris Medical, Isny, Germany) (Fig. 3). The instrument recorded the spatial displacement of the mandible in a

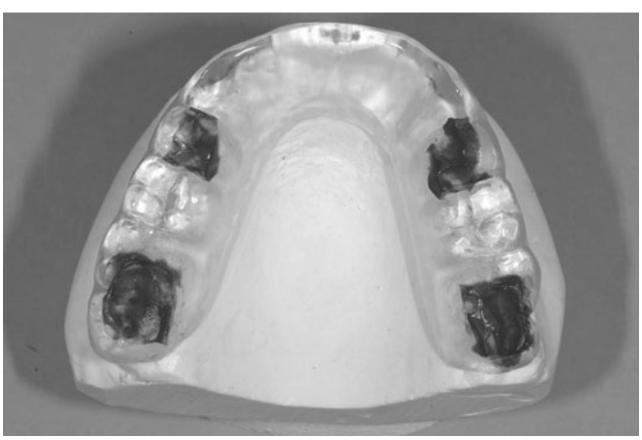

Fig. 2 Intraoral acrylic device simulating a prosthetic reconstruction. Premolar and molar regions are relined with pattern resin for stabilisation of the bite

coordinate system in which the *x*-, *y*- and *z*-axes represented anteroposterior, vertical and transverse displacement, respectively, and negative values denoted posterior, left and caudal displacement, respectively. The coordinate system was determined by a plane parallel to the mandibular hinge axis and by the deepest point of the right orbita (hinge axis–orbital plane). The hinge axis was calculated by means of the measurement system, on the basis of rotational open and close movements guided by the examiner. The measurement points used for the analysis were: (a) two points on the hinge axis of the mandible symmetrically located at a distance of 5.5 cm from the midsagittal plane (representing the right and left condyles as virtually reconstructed by the measurement system's software); (b) two points on the buccal side of the first lower molars, bilaterally; and (c) one incisal point, defined as between the lower first incisors.

The spatial coordinates of the hinge axis–orbital plane were defined for IC by means of the right side infraorbital point and the two hinge axis points (see above). Infraorbital, molar and incisal points were located by means of a special metal pin integrated in the lower bow of the ultrasonic device (Fig. 3). On the basis of these reference points, the software of the system calculated the new coordinates of the five mandibular points for each of the next recordings, i.e. BR and OD. The displacements at the particular locations of the mandible in the BR and OD positions were computed as differences from the IC position as the reference measurement.

EMG measurement and feedback

Bipolar Ag/AgCl surface electrodes, diameter, 14 mm and centre-to-centre distance, 20 mm (Noraxon Dual Electrodes, Noraxon, Scottsdale, USA), measured, bilaterally, the EMG activity of the masseter and anterior temporalis. The electrodes were placed parallel to the longitudinal axis of the muscles. Before application of the electrodes, the skin was cleaned with 70% ethanol. The common electrode was positioned in the neck above the seventh vertebra. The EMG signals were differentially amplified (EM 100 Biopac, Santa Barbara, CA, USA; frequency response 1–5,000 Hz) and sampled at 1,000 Hz simultaneously with the force signals.

To obtain feedback signals from the masseter, two additional bipolar electrodes were placed directly behind the recording electrodes and connected by a parallel circuit to a separate EMG amplifier (Fig. 4). The rectified signal was displayed to the subjects on a monitor. A horizontal guide on the display enabled adjustment of the different EMG activity levels relative to maximum voluntary clenching (MVC).

EMG and jaw position recording

After application of the EMG electrodes, the subjects performed three maximum-effort bites in intercuspation,

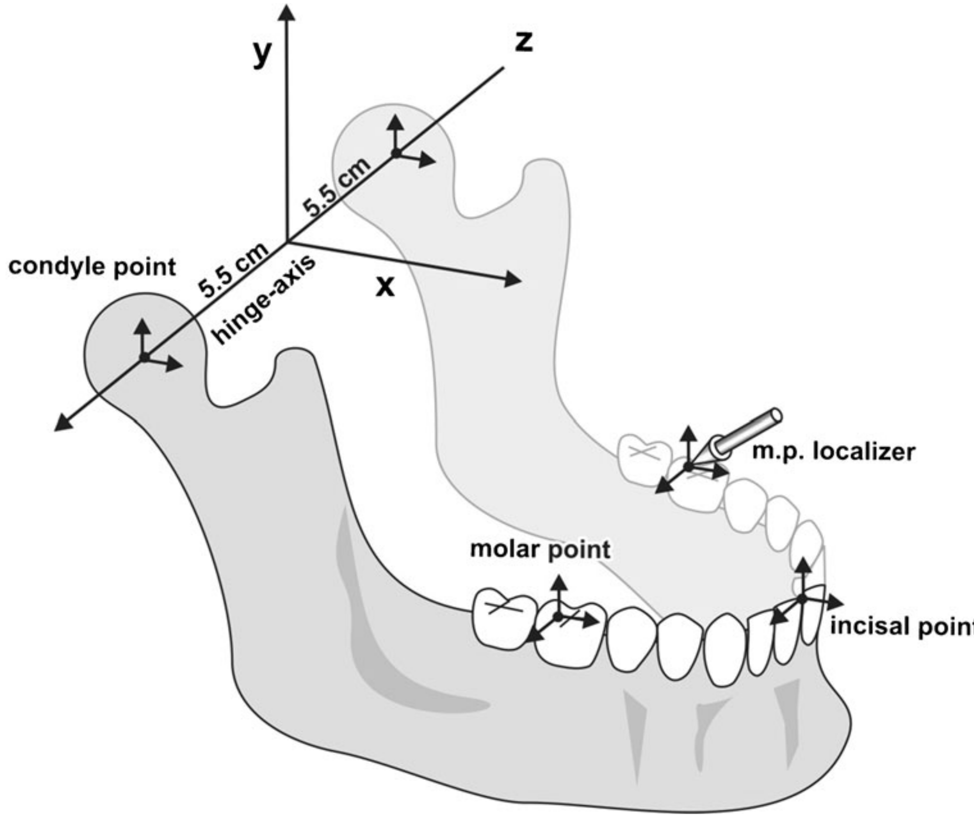

Fig. 3 Measurement points of the mandible; *m.p. localizer* measurement point locator integrated in the lower bow of the ultrasonic device

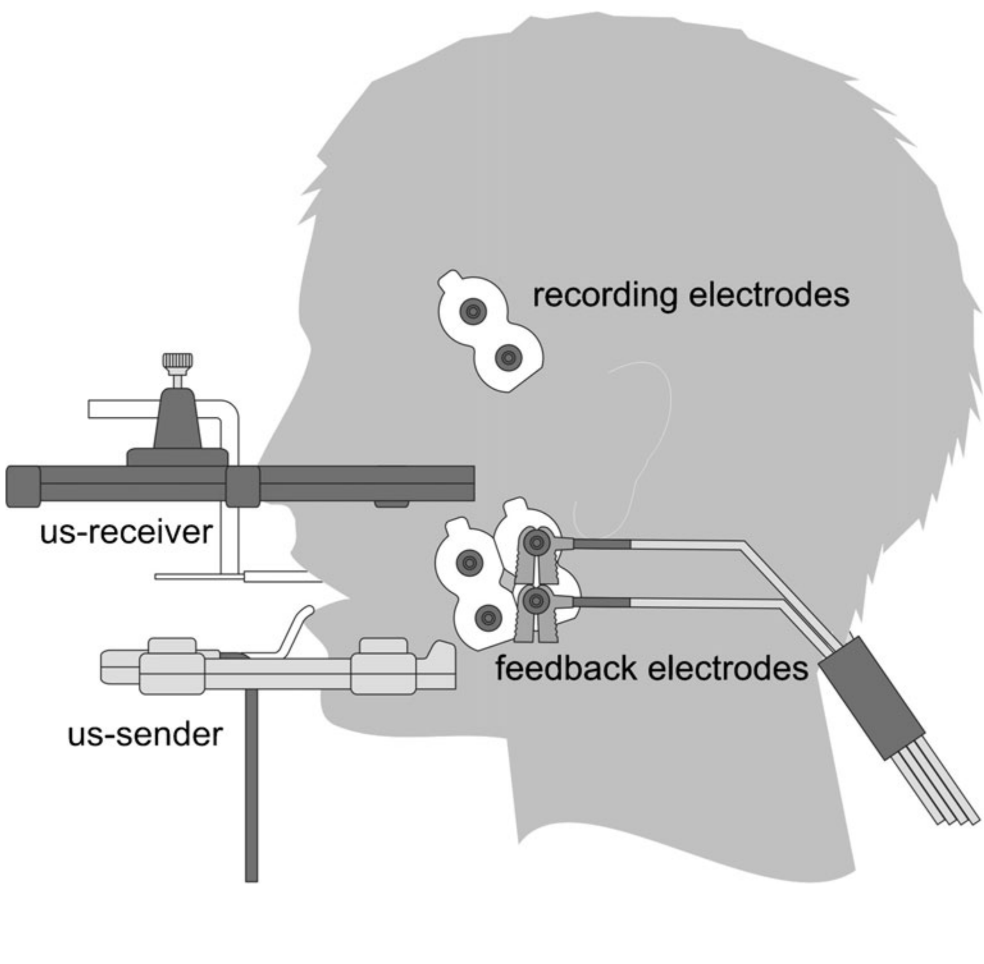

Fig. 4 Ultrasonic measurement device and location of the feedback electrodes; *us* ultrasonic

holding the activity level for 2 s. The rectified and averaged data were used as reference values for the feedback, displayed during the submaximum EMG activation. In the next step, the ultrasonic device was attached to the upper and lower labial surfaces of the teeth by means of a paraocclusal attachment, which was fixed with superglue. The hinge-axes of the mandible, condyle, molar and incisal measurement points in the different mandibular positions were determined with the aid of a special software tool of the ultrasonic measurement system. Measurement of the positions of the mandible was performed in the sequence IC, BR and OD. The recordings were started when the test person achieved the specific EMG value of 25% MVC. All measurements were replicated three times. To elucidate potential differences between EMG activity of the homonymous and heteronymous muscles while biting in the jaw positions IC, CR and OD, three additional EMG recordings were made with 25%, 50% and 100% MVC after removal of the kinematic measurement system.

Data analysis

The accuracy of the ultrasonic measurement system was tested with an x, y and z stage for the range of displacements relevant to this study (anteroposterior x=+2 to −5 mm; vertical y=+2 to −7 mm; left/right z=+2 to −2 mm). The accuracy of the measurement chain (precision of the instrument, procedural errors of the replicate readings) was determined as follows. The absolute value of the spatial displacement vector caused by the experimental jaw relations (BR and OD) was computed for each subject, for all replicates of the specific experiments, by use of the formula $d = \sqrt{x^2 + y^2 + z^2}$. The absolute values of the differences between the three replicate measurements (rm1−rm2; rm1−rm3; rm2−rm3) were then calculated and averaged [12]. The mean and standard deviations (SD) for all the absolute displacements computed for the five mandibular measurement points (right and left condylar, right and left molar and incisal points) were used to describe the global quantitative accuracy of the measurement chain. To evaluate the accuracy with which BR was reproduced in the OD position, differences between BR and OD were also described by the absolute spatial displacement of the incisal point and of the averaged (right, left) condylar and molar points.

The displacement coordinates of the five investigated mandibular measurement points caused by the incorporated BR and OD devices were described as differences from IC. The results from the three replicates of the recorded jaw positions were averaged. The displacement differences between the three jaw positions were expressed as mean values (mean) and SD separated for the right and left sides and for the pooled data. The statistical significance of differences was investigated by one-way and two-way repeated measures ANOVA and subsequent Bonferroni-adjusted post hoc tests.

The raw EMG data obtained from the four muscles monitored were rectified by use of the root mean square algorithm and simple ratios were calculated for the left and right muscles [23]. The results from the three replicates of the different biting tasks were averaged and expressed as mean values (mean) and SD. Differences between the right/left activation ratios of the temporalis (Tp) and masseter (Ma) muscles and the Tp/Ma ratios under these experimental conditions (IC, BR and OD; 25%, 50% and 100% MVC) were investigated by use of one-way repeated measures ANOVA and subsequent Bonferroni-adjusted post hoc tests. SigmaStat 3.5 (Systat Software GmbH, Erkrath, Germany) was used for statistical analysis. The value α=0.05 was used as the significance level.

Results

Displacement measurements

The accuracy of the ultrasonic measurement system was 0.01 mm for the range of mandibular displacements recorded in this study. The mean quantitative accuracy of the measurement chain was 0.11±0.08 mm.

The mean and SD for the five mandibular locations are listed in Table 1. The BR and OD displacement coordinates (with the exception of the z coordinates) for the five mandibular locations differed significantly ($p<0.05$) from the IC coordinates.

The condylar displacement of the right and left sides differed significantly ($p<0.001$) between BR and OD for the vertical displacement (Table 1). The averaged displacement difference of the y-component between BR and OD amounted to approx. 0.3 mm, i.e. the condyles were located more caudally in OD than in BR. There was, however, also a significant ($p<0.05$) difference between the right and left condylar displacements within BR and OD for the y-component. Compared with IC, the averaged (left/right) displacement directions of the condyles lay approximately 0.6±0.7 mm cranial and 0.4±0.5 mm posterior for BR and approximately 0.3±0.8 mm cranial and 0.5±0.6 mm posterior for OD.

The molar displacement of the right and left sides differed significantly ($p<0.001$) between BR and OD for the displacement of the right side only (Table 1). The averaged displacement difference of the y-component between BR and OD amounted to approx. 0.3 mm, i.e. the molars were located more caudally in OD than in BR. No significant differences were observed between the left and right molar displacements within BR and OD.

The incisal displacement also differed significantly ($p<$ 0.05) between BR and OD (Table 1). The displacement

Table 1 The coordinates of the displacements (in millimeters) measured in the condyle, molar and incisal regions of the mandible relative to IC after bite recording or incorporation of intraoral devices

	BR			OD		
	x	y	z	x	y	z
Right condyle						
Mean	−0.37	0.71	−0.02	−0.36	0.45	−0.02
SD	0.45	0.77	0.27	0.50	0.87	0.24
Left condyle						
Mean	−0.52	0.45	−0.01	−0.53	0.20	−0.02
SD	0.60	0.70	0.27	0.62	0.65	0.24
Right molar						
Mean	−2.99	−3.03	0.03	−3.03	−3.32	−0.01
SD	0.70	0.96	0.39	0.72	1.05	0.45
Left molar						
Mean	−3.12	−3.13	0.03	−3.19	−3.42	0.01
SD	0.82	1.02	0.40	0.81	1.08	0.47
Incisal						
Mean	−4.27	−4.95	0.05	−4.35	−5.25	0.03
SD	1.23	0.83	0.55	1.25	0.96	0.62
Pooled data						
Condyles						
Mean	−0.44	0.58	−0.01	−0.45	0.33	−0.02
SD	0.53	0.74	0.26	0.57	0.77	0.24
Molars						
Mean	−3.06	−3.08	0.03	−3.11	−3.37	0.00
SD	0.76	0.99	0.39	0.77	1.06	0.46

Results for right and left sides are listed separately and as the mean for both sides; negative values are posterior, left and caudal displacements, respectively

BR bite recording, *OD* occlusal device; *x* anteroposterior displacements, *y* vertical displacements, *z* transverse displacements, SD standard deviation

difference of the *y*-component between BR and OD amounted to approx. 0.3 mm, i.e. the incisal point was located more caudally in OD than in BR. No significant deviations were observed for the other spatial coordinates.

The mean absolute spatial displacement differences between BR and OD at the incisal point and at the condylar and molar points, averaged over the right and left sides, are illustrated in Table 2. The differences, approximately 0.3 mm, were similar for the three measurement points.

EMG

Table 3 shows the mean and SD of the right/left side activation ratios for the masseter and temporalis muscles. Between BR vs. OD and IC vs. OD, the ratios were significantly ($p<0.05$) different for the temporalis muscle at 50% MVC only. The mean differences at 25% MVC were in the same range but did not reach significance. No significant differences were detected between IC and BR for either the temporalis or masseter muscles. The experiments on the three jaw relations executed with 100% MVC revealed no significant differences.

Table 2 The mean absolute spatial displacement differences (in millimeters) between BR and OD for the incisal point and the condylar and molar points averaged over the right and left sides

	Spatial differences between BR and OD		
	Condyle	Molar	Incisal
Mean	0.32	0.32	0.36
SD	0.35	0.25	0.27

BR bite recording, *OD* occlusal device, *SD* standard deviation

Table 4 summarises the Tp/Ma activity ratios under the three loading conditions. Because no significant differences could be observed, left and right side data were averaged. The Tp/Ma activity ratios between IC, BR and OD differed significantly ($p<0.05$) within all identical loading tasks (beside IC vs. OD at 100% MVC). The ratios between the various loading tasks within the groups also differed significantly in such a way that the unequal ratios at 25% MVC became, in ascending order, almost equal to those at 100% MCV.

Discussion

This study was conducted to assess the accuracy of transfer of bite recording to simulated prosthetic reconstructions. The main result of the investigation was the finding that in experimental simulation of prosthetic treatment by use of an

Table 3 Summary of the right/left activity ratios of the temporalis and masseter muscles under the three loading conditions (IC, intercuspation; BR, bite recording; OD, occlusal device) with 25%, 50% and 100% of maximum voluntary contraction (MVC)

	25%		50%		100%	
	Tp	Ma	Tp	Ma	Tp	Ma
IC						
Mean	1.13	1.06	1.08	0.93	1.03	0.96
SD	0.46	0.99	0.37	0.35	0.31	0.35
BR						
Mean	1.09	1.11	1.09	1.05	1.06	0.96
SD	0.38	0.56	0.36	0.42	0.27	0.29
OD						
Mean	1.25	1.10	1.23	1.03	1.07	0.98
SD	0.64	0.60	0.57	0.50	0.25	0.28

Tp temporalis, *Ma* masseter, *SD* standard deviation

Table 4 Summary of the temporalis/masseter activity ratios under the three loading conditions (IC, intercuspation; BR, bite recording; OD, occlusal device) with 25%, 50% and 100% of maximum voluntary contraction (MVC)

	25% Tp/Ma	50% Tp/Ma	100% Tp/Ma
IC			
Mean	1.50	1.16	1.00
SD	1.26	0.76	0.39
BR			
Mean	1.58	1.24	1.07
SD	0.83	0.60	0.39
OD			
Mean	1.19	1.07	0.98
SD	0.76	0.55	0.37

Tp temporalis, *Ma* masseter, *SD* standard deviation

acrylic splint even inexperienced dental students are able to replicate the recorded jaw relation with clinically acceptable spatial accuracy of approximately 0.3 mm (Table 2), i.e. the measured values were within the range previously reported for replication accuracy (0.3 to 0.4 mm) for a variety of intraoral bite recording techniques [12].

It is difficult to compare the results from this study with those from the literature [5–12] because (a) different methods and statistical analysis were used to calculate accuracy and (b) our study compared centric jaw relations with “simulated restorations” and not with replicated centric relation of the condyles only, as in previous investigations. The accuracy of replicated centric relation records provides a basic measure of clinically unavoidable tolerances for the complete prosthetic procedure, however. Furthermore, previous data were obtained under different methodological constraints, for instance, by direct or indirect measurements and with variable forces applied during recordings or bite registration. In this study, both bite recording and the position of the “simulated prostheses” were measured intraorally for controlled bite forces. This method avoided measurement errors caused by all extraoral technical procedures and provided realistic in situ data. In this context, the statistical method used in this study, adopted from a paper mentioned above [12], seems to be an appropriate method for describing accuracy using a single measurement, because it uses an absolute value for the spatial displacement. The absolute values provide a more realistic estimate of precision than the values of the single displacement vectors used in most studies. Single components underestimate the real extent of spatial displacement. To demonstrate the direction of the displacement, however, information about displacement vectors is also needed.

The averaged displacement coordinates of the condyles between the IC and BR positions revealed differences in the *x*- and *y*-directions of approximately 0.5 and 0.6 mm, respectively. This is in the range of displacements reported for commonly used clinical centric relation recording techniques [1–3]. In the OD position, the condyles moved in relation to BR approximately 0.3 mm in the caudal direction (*y*-component) and thus closer to IC. The *x*-component, however, remained stable. Caudal displacement of the *y*-component relative to BR of approximately 0.3 mm was also found in the molar and incisal regions. This can be explained as follows: the condyles were slightly displaced caudally during selective grinding for occlusal adjustment, for instance, because of less forceful posterior manual guidance of the mandible by the examiner when performing this procedure. As a result, the contact areas of the mandibular cusps were slightly displaced anteriorly on to cusp inclinations of the structured devices. This, in turn, caused caudal displacement in OD compared with BR for incisal, molar and condylar reference points, as found in this study. Another possibility, as recently described [24], might be the caudal displacement of the condyles caused by premolar contacts during occlusal adjustment. Presumably, the forces on the chin manipulated by the examiner rotated the mandible in a clockwise manner around a transverse axis intersecting the premolar region (in contrast, molar contacts and the corresponding transverse axis induced counterclockwise rotation of the mandible in this study). Small errors in the technical procedure might also have affected caudal displacement of the mandible in OD compared with the BR relation. In particular, small differences between the fit of the OD on the casts and that on the upper dentition of the subjects may have resulted in additional vertical discrepancies. Furthermore, the relining of the OD with pattern resin in the four discrete contact areas might also have caused slight vertical displacement of the mandible (a known phenomenon after cementation of fixed restorations). In conclusion, the listed possible methodological causes of jaw relation differences between BR and OD might basically correspond to error sources which also occur for real prosthetic cases.

A limitation of the study design might be that the ultrasonic recordings were performed under conditions of standardised bite force, controlled by EMG, whereas intraoral occlusal adjustments by selective grinding were not force controlled. This might also have affected the final jaw relation in OD. This shortcoming is, however, also present in daily clinical routine. Therefore, we suppose that the experimental design simulated a realistic clinical procedure. In addition, it might be argued that the intraoral devices were adjusted by dental students with little practical experience and that experts would achieve better results. This, again, may be true but the intention of this study was to investigate clinical precision in realistic, not ideal, circumstances. On the other hand, as mentioned in other studies, experts achieved accuracy with replicated recording techniques which lay in the range of the differences between BR and OD found in this study.

The significant left and right asymmetries between BR and OD in the condylar region, in the context of the previously described variability of bite recording accuracy (approx. 0.3 to 0.4 mm spatial deviation) for different techniques [12], and the variance of the replication of BR in OD found in this study (approx. 0.3 mm spatial deviation for condylar, molar and incisal regions) have another crucial clinical implication. These findings essentially question the belief that repositioning of the mandible in centric relation, interpreted as the physiologically or biomechanically optimum position [25, 26], is an important aspect of the therapeutic effects of, e.g. occlusal splint therapy, occlusal adjustment or so-called phase II prosthetic rehabilitation of temporomandibular disorder patients. It must be considered that such intervention needs bite recording and/or jaw guiding during occlusal equilibration, i.e. it is performed under conditions in which kinematic and biomechanical rules and errors are identical. Assuming such intervention may actually have a specific therapeutic effect; the obvious variability of the technical procedures leads to the only realistic conclusion that modification of the jaw position may be the most important aspect, presumably by changing the intra and intermuscular recruitment patterns or loaded joint regions [27, 28] and not by any (physiologically and/or biomechanically) *optimum* repositioning of the mandible. Furthermore, the results support the idea of excellent adaptability of the neuromuscular system not only for healthy subjects but also for patients because both have to adapt to the shortcomings of bite recording or occlusal adjustment procedures.

Under 50% MVC, the EMG recordings revealed significant asymmetric contraction patterns for OD compared with BR and IC for the temporalis muscles but not for the masseter muscles. The values of the ratios with 25% MVC were similar to those observed for 50% MVC, but they did not reach significant levels. Comparison of BR and IC did not replicate these phenomena. In addition, the Tp/Ma ratios differed significantly among IC, BR and OD for almost all identical loading conditions. These findings may be explained by variable proprioception in IC, BR and OD, because of the different occlusal support. The observed variable contraction behaviour is in agreement with recent findings in experimental occlusion that small jaw gap changes caused significant activity changes between the left and right masticatory muscles [19]. Likewise, it confirms differential contraction behaviour between temporalis and masseter under comparable conditions, e.g. anteroposterior jaw displacements. All these findings also emphasise the significance of the temporalis as a coordination muscle [29]. In contrast with IC and BR, two modified contraction patterns could be observed for OD. First, the activation ratio between the right and left side musculature changed at 100% compared with 25% and 50% MVC, and, second, the Tp/Ma ratio differences between the various loading conditions were less pronounced than within IC and BR. These phenomena might be explained by shifts of neuromuscular control strategies under the maximum loading conditions, combined with the complex proprioceptive input triggered by the unfamiliar occlusion of OD. In summary, these observations correspond to previous findings of asymmetric contraction ratios under low bite forces, in contrast with higher force levels [30]. In the context of prosthetic reconstruction, the neuromuscular system must adapt well to small jaw gap differences between both jaw sides in the range found in this study. The reason is that, although a 10-μm shimstock is held between the teeth, occlusal adjustment cannot affect jaw gap differences of unknown magnitude.

Conclusions

In conclusion, these findings revealed that centric jaw relation, recorded by a specific bite recording technique, may be reproduced by a specific prosthetic reconstruction with the accuracy of replicated intraoral bite recording reported for different recording techniques.

Conflicts of interest The authors declare that they have no conflict of interest.

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