Midline Mandibular Deformation During Nonmasticatory Functional Movements in Edentulous Subjects with Dental Implants

Ali M. El-Sheikh, MSD, MSc, PhD[1]/Hind H. Abdel-Latif, BDS, MSc, PhD[2]/Peter G. T. Howell, BSc, BDS, PhD[3]/
John A. Hobkirk, PhD, BDS, FDS RCS (Eng), FDS RCS (Edin)[4]

Purpose: *Mandibular deformation during function in patients with implant-supported prostheses is associated with increased strain at the bone-implant interface when dental implants are connected by a relatively rigid superstructure. Whilst there is a body of evidence concerning deformation as measured between the corpora, there are little data on its effects in the midline. This study measured 3 types of midline mandibular deformation during nonmasticatory functional mandibular movements in edentulous subjects with dental implants.* ***Materials and Methods:*** *A range of custom displacement transducers was fabricated for 5 edentulous subjects who had been treated with dental implants in the anterior mandible. These transducers were mounted on contralateral implant abutments adjacent to the midline to measure medial convergence, corporal rotation, and anteroposterior shear. Their output was recorded for offline analysis by a personal computer.* ***Results:*** *The values of medial convergence ranged from 15 to 42 µm during opening, from 10 to 21 µm during lateral excursions, and from 18 to 53 µm during protrusion. Corporal rotation varied from 0.05 to 0.11 degrees during opening, from 0.03 to 0.08 degrees during lateral excursions, and from 0.03 to 0.15 degrees during protrusion. Anteroposterior shear varied from 38 to 93 µm during opening, from 28 to 56 µm during lateral excursions, and from 52 to 103 µm during protrusion.* ***Discussion and Conclusions:*** *Nonmasticatory physiological mandibular movements cause the jaw to deform about the midline in at least 3 directions. It is important for the clinician to be aware of the phenomenon of mandibular deformation, which should be taken into consideration in the design and monitoring of mandibular prostheses.* INT J ORAL MAXILLOFAC IMPLANTS 2007;22:243–248

Key words: *dental implants, edentulous subjects, mandibular deformation*

Several studies have shown that deformation of the mandible occurs in dentate[1–4] and edentulous[5,6] subjects during active jaw movements. Hylander[7] described 4 types of deformation at the mandibular symphysis. They were

1. Bending caused by medial and lateral bending of mandibular corpora
2. Shear caused by dorsoventral shear and anteroposterior shear
3. Bending associated with twisting of the mandibular corpora about their long axes
4. Twisting about the transverse axis of the symphysis

Mandibular deformation may result in changes in the relationships of the dental arch across the midline. This phenomenon might be of considerable importance considering the use of implant-stabilized prostheses that use a relatively rigid host-implant interface combined with extensive fixed restorations. In these circumstances it has been conjectured that the resultant strains could lead to premature failure at the osseointegrated implant interface or of the superstructure itself.[8] Information on the magnitude of these types of deformation is integral to understanding the biomechanics of dental implants. How-

[1]Lecturer, Department of Prosthetic Dentistry, Faculty of Dentistry, Tanta University, Tanta, Egypt.
[2]Postdoctoral Research Fellow, Division of Restorative Dental Sciences, UCL Eastman Dental Institute, University College London, United Kingdom.
[3]Senior Lecturer, Division of Restorative Dental Sciences, UCL Eastman Dental Institute, University College London, United Kingdom.
[4]Chairman, Division of Restorative Dental Sciences, UCL Eastman Dental Institute, University College London, United Kingdom.

Correspondence to: Professor JA Hobkirk, UCL Eastman Dental Institute, University College London, 256 Gray's Inn Road, London WC1X 8LD, UK. Fax: +44 0207 915 1246. E-mail: j.hobkirk@eastman.ucl.ac.uk

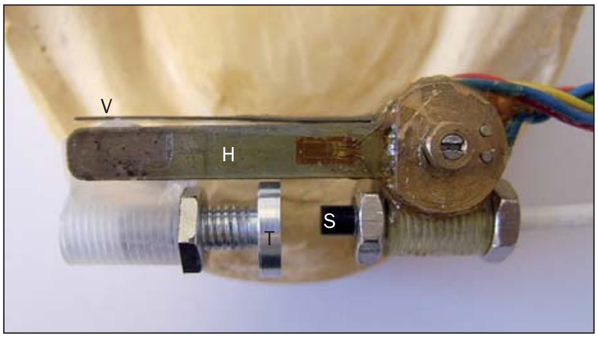

Fig 1 The sensor (S) of the inductive transducer measuring medial convergence. The sensor detects its distance from the aluminum target (T). The horizontal beam (H) was used to measure corporal rotation and the vertical beam (V) to measure anteroposterior shear.

Table 1 Gender, Age, and Implant Separation for Each Subject

Subject no.	Gender	Age (y)	Implant separation (mm)	Intergonial distance (mm)	Symphyseal height (mm)
1	F	48	23	100	18
2	F	62	24	92	17
3	F	74	28	90	19
4	F	78	33	97	21
5	M	70	31	113	23

ever, few data are available on mandibular deformation in edentulous subjects, and anteroposterior shear has yet to be measured in humans.

The aim of this study was therefore to measure 3 types of midline mandibular deformation—medial convergence, corporal rotation, and anteroposterior shear—during nonmasticatory functional mandibular movements in a group of edentulous subjects who had been successfully treated with dental implants.

MATERIALS AND METHODS

A group of 5 edentulous subjects, 4 women and 1 man, with a mean age of 66.4 years (SD ± 11.9 years; range, 48 to 78 years) entered this study. No subject had any evidence of TMJ dysfunction or local or systemic diseases that might have influenced neuromuscular activity. All subjects were patients of the Department of Prosthetic Dentistry, Eastman Dental Hospital, London, and had been treated by the placement of at least 2 dental implants (Nobel Biocare, Göteborg, Sweden), located symmetrically around the midline in the anterior region of the mandible to retain implant-stabilized overdentures. These implants were used as mounting points for displacement transducers. Symphyseal height and width were determined from lateral skull radiographs[5] (Table 1). The width of each jaw for each subject was measured across the gonial angles using calipers, and this value was then corrected by subtracting skin-fold thickness. All subjects gave informed consent to participate in the study, which was approved by the local research ethics committee.

Deformation Measurements

Medial convergence was measured using an inductive displacement transducer (KMD-7200; Kaman Instrumentation, Colorado Springs, CO) as the change in the bodily separation of 2 contralaterally placed implants (Fig 1). The magnetic sensor was fixed with acrylic resin to a modified square impression coping, which was screwed via a transmucosal abutment to the implant on 1 side of the arch. A target of polished aluminum was similarly fixed to the contralateral implant. This device was aligned to lie horizontally across the midline and perpendicular to the midsagittal plane. The system operates by measuring the changes in magnetic field induced by an alternate current (AC) -powered coil in the sensor as it approaches the target.

Corporal rotation was measured in the transverse plane as the rotation of contralateral implants relative to their apices. Such rotation could cause the top of 1 implant to move toward or away from the other. This movement was determined using a horizontal steel beam attached to a strain gauge (No.632-124, RS Ltd; Corby, Northamptonshire, UK). The beam was fixed on 1 implant and resting on the top of the contralateral implant[6] (Fig 2a). The beam did not lie passively at rest but applied a slight downward pressure so as to avoid backlash and to maintain contact with the bearing point on the contralateral implant. Relative movement between the 2 implants caused deformation of the beam and hence the strain gauge. These changes could be measured accurately and, after suitable calibration, used to calculate the relative change in position of the implant.

Corporal rotation, θ, was then derived from the following equation:

$$\tan(\theta) = d/L$$

where d is the relative vertical displacement of the implant and L is the distance between the implants (Fig 2a).

Anteroposterior shear was measured in the midsagittal plane perpendicular to the occlusal plane. This movement incorporates a component of dorsoventral shear (Figs 2a and 2b). It was measured as the relative backward movement of 1 implant relative to its contralateral counterpart using a second strain-gauged steel beam (No.632-124; RS Ltd). This

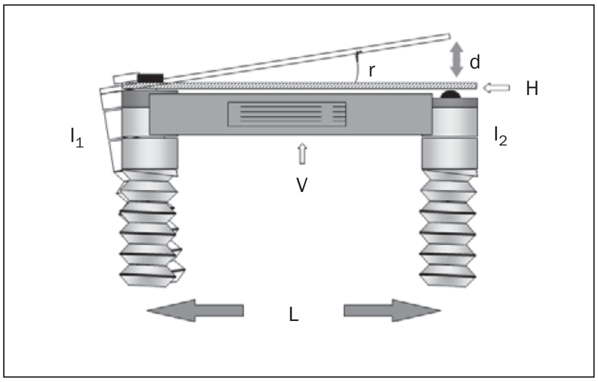

Fig 2a Front elevation of 2 implants, I_1 and I_2, showing the method used to measure corporal rotation and the location of the beam for determining anteroposterior shear. H = cantilever strain-gauge beam (horizontal beam); V = vertical transducer beam; d = effective vertical movement of end of beam due to corporal rotation; L = distance between implants; r = corporal rotation angle.

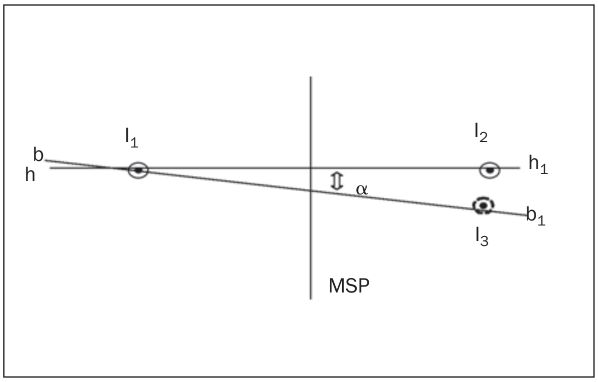

Fig 2b Schematic view of implants showing the principle used to calculate anteroposterior shear. I_1 and I_2 = position of implants prior to anteroposterior shear; I_3 = effective position of I_2 relative to I_1, after anteroposterior shear. Line hh_1 = line joining implants prior to anteroposterior shear; line bb_1 = line joining implants after anteroposterior shear. α = effective relative movement of implants at transducer level as projected onto the median sagittal plane (MSP).

second transducer was mounted vertically on 1 implant; it rested on the opposite implant (Fig 3). The beam did not lie passively at rest but applied a small forward pressure on the opposing transmucosal abutment (TMA), which ensured that the beam and the TMA always remained in contact.

The 2 strain gauges were connected in a half-bridge configuration, and their outputs, together with that from the displacement transducer measuring medial convergence, were logged by a personal computer running commercial data capture and processing software (Microlink Products; Bio Data, Manchester, UK). All transducers were calibrated before and after each recording session. The transducers were fabricated individually for each subject on the original laboratory casts used to prepare their implant-supported overdentures.

Each subject was comfortably seated in the chair in an upright position with his or her head resting against the head support. The dentures and the implant-retained superstructure were removed, and the measurement transducers were fixed in place. The electrical circuits were adjusted to zero when the patient was completely relaxed and the mandible was in its rest position. After a brief training session, data recording was initiated, and the subject carried out the following directed mandibular movements:

- Maximum opening
- Maximum right lateral excursion
- Maximum left lateral excursion
- Maximum protrusion

After each movement the subject was asked to return the mandible to a relaxed central position.

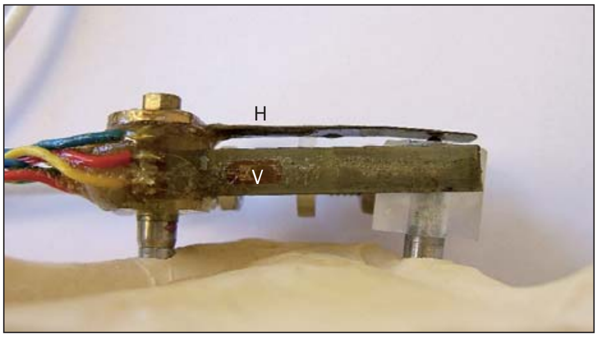

Fig 3 The vertical beam, V, was used to measure anteroposterior shear, and the horizontal beam, H, to measure corporal rotation.

This sequence was repeated 5 times for each movement, with an interval of 1 minute between each recording.

Statistical Analysis

Raw data were entered into Microsoft Excel (Microsoft, Redmond, WA) and collated before being transferred to SPSS (SPSS, Chicago, IL) for statistical analysis.

The data were initially tested using an analysis of variance (ANOVA) with post-hoc Bonferroni tests to establish whether there was any difference between the 3 parameters measured as a result of the directed jaw movements performed by the patient. *P* values less than .05 were considered significant. This demonstrated that while there were differences between the 4 tasks, there was no significant difference ($P < .05$) between the data for left and right lateral excursion. The data for left and right lateral excursion were therefore pooled, and subsequent statistical tests were based upon this pooled dataset.

RESULTS

Mandibular deformation occurred during all the mandibular movements studied, and the 3 deformations measured in this study occurred concurrently.

Medial Convergence

The mean medial convergence for the 5 subjects in this study was 33.5 μm in protrusion (range, 17.7 to 52.7 μm); 28.2 μm during maximal opening (range, 14.7 to 42.2 μm), and 15.7 μm in lateral excursion (range, 10.2 to 21.0 μm; Table 2). These differences resulting from the directed action were highly significant ($P < .001$). For each of the 5 subjects, except for subject 5, the greatest medial convergence was found during protrusion and the least during lateral excursion, with maximum opening giving intermediate results in most cases (Fig 4). ANOVA showed that there were significant differences ($P < .001$) in the data related to the individual subject, and the post-hoc tests showed that the subjects fell into 2 groups: Subjects 1, 2, and 5 could be grouped together, and subjects 3 and 4 could be grouped together. Within each group there was no significant difference ($P > .05$); however, there was a significant difference ($P < .001$) between the 2 groups of subjects.

Corporal Rotation

The mean corporal rotation found in this study was 0.087 degrees in protrusion (range, 0.031 to 0.147 degrees), 0.082 degrees during maximal opening (range, 0.053 to 0.112 degrees), and 0.042 degrees in lateral excursion (range, 0.025 to 0.080 degrees; Table 3). Corporal rotation during lateral excursion was significantly different ($P < .001$) from that found during maximum opening and protrusion. Corporal rotation was not significantly different at maximal opening compared with protrusion ($P > .05$). For 4 of the 5 subjects the greatest corporal rotation was found during protrusion and the least during lateral excursion, with the data from maximal opening being intermediate (Fig 5). ANOVA showed that there were significant differences ($P < .001$) in the data related to the individual subject, and the post-hoc tests showed that the subjects fell into 2 groups: Subjects 1 and 2 could be grouped together, with subjects 3, 4, and 5 in the other group. Although there were no significant differences within either group ($P > .05$), there was a significant difference ($P < .001$) between the 2 groups of subjects.

Anteroposterior Shear

The mean anteroposterior shear was found to be 88.1 μm in protrusion (range, 52.4 to 102.9 μm); 56.8 μm during maximal opening (range, 37.6 to 93.0 μm), and 41.9 μm during lateral protrusion (range, 28.2 to 55.9 μm; Table 4). The data resulting from the directed movement were found to be significantly different ($P < .001$) from one another. While all 5 subjects were found to have the greatest anteroposterior shear during protrusion, only 4 of the 5 had the least during lateral movements, with intermediate data found during maximum opening (Fig 6). There were differences between the individual subjects, but they did not show any consistent pattern.

DISCUSSION

Natural teeth have a mobility associated with the periodontal membrane, which makes them less useful for the accurate establishment of mandibular deformation. Determining these distortions in edentulous subjects is made relatively easy when rigid osseointegrated implants are used to form a stable base from which to make measurements. Indeed, it is these individuals for whom data should be established, as it is they who will be at the highest risk of failure of the implant-bone interface or of the rigid superstructure, through strains generated during normal functional and nonfunctional mandibular movements.

The advantage of the displacement transducers used in this study was the ability to collect deformation data simultaneously. Although each transducer was intended to measure a single mode of mandibular deformation, the interrelationships between the different types of deformation cannot be neglected. The transducers, did not function in total isolation; all were recording vectors of a complex pattern of mandibular distortion. The design of the transducer for anteroposterior shear minimized the effects of dorsoventral shear, which, if the system were symmetrical about the midline, would register zero displacement in the MSP.

The medial convergence recorded in this study was much less than that recorded in previous studies and probably reflected the anterior positioning of the transducers. In addition, with the exception of Hobkirk et al,[5] Horiuchi et al,[9] and Abdel-Latif et al,[6] previous investigators have linked the measuring devices to natural teeth, which would have been less stable than integrated implants.

The corporal rotation angles recorded in this study were somewhat lower than those recorded by Abdel-Latif et al,[6] who measured the deformation between the implants placed in the premolar region, while in this present study the implants were placed in the anterior region of the mandible.

Table 2	Medial Convergence in μm (n = 5)			
	Mean	Range	SD	95% CI
Opening	28.2	14.7 to 42.2	11.7	10.2
Lateral	15.7	10.2 to 21.0	5.0	4.4
Protrusion	33.5	17.7 to 52.7	15.5	13.6

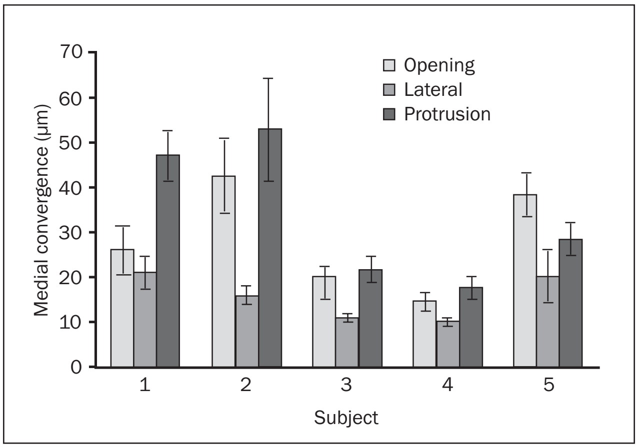

Fig 4 Medial convergence (μm). The mean (± 95% CI) for each subject during opening, protrusion, and lateral excursion.

Table 3	Corporal Rotation in Degrees (n = 5)			
	Mean	Range	SD	95% CI
Opening	0.082	0.053 to 0.112	0.027	0.024
Lateral	0.042	0.025 to 0.080	0.022	0.019
Protrusion	0.087	0.031 to 0.147	0.050	0.044

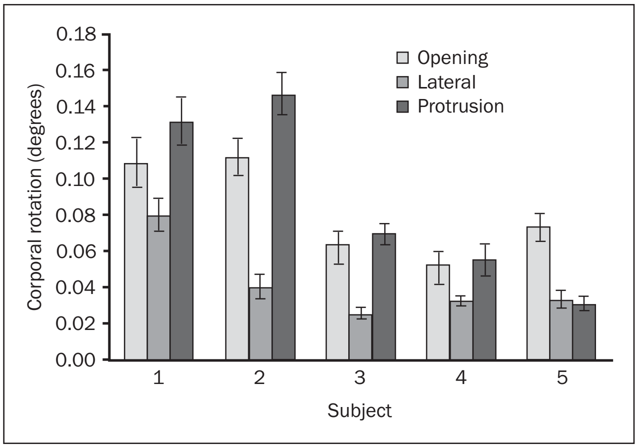

Fig 5 Corporal rotation (degrees). The mean (± 95% CI) for each subject during opening, protrusion, and lateral excursion.

Table 4	Anteroposterior Shear in μm (n = 5)			
	Mean	Range	SD	95% CI
Opening	56.8	37.6 to 93.0	21.5	18.9
Lateral	41.9	28.2 to 55.9	9.9	8.7
Protrusion	88.1	52.4 to 102.9	21.6	18.9

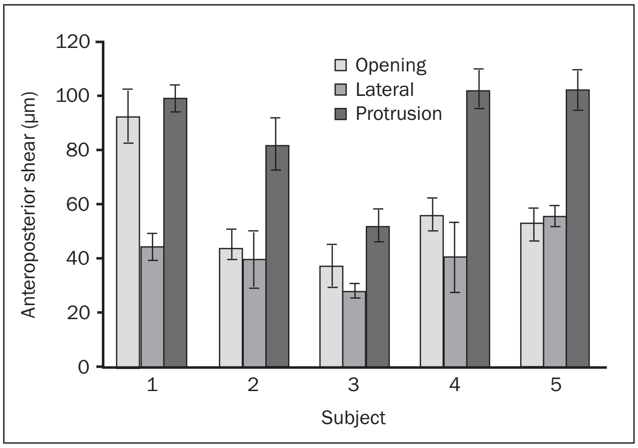

Fig 6 Anteroposterior shear (μm). The mean (± 95% CI) for each subject during opening, protrusion, and lateral excursion.

Anteroposterior shear has not previously been reported in human subjects. It was found to vary both with the directed action and the individual subject. The variation in the values of each type of mandibular deformation is probably related to subject variations and inconsistencies in the range of jaw movements during the experiment, although subjects were asked to make maximum excursions.

The apparent lack of a relationship between medial convergence and implant separation, symphyseal height, and intergonial distance may reflect the relatively small size of the sample as well as a multiplicity of other variables. These include the shape of the anterior mandible as seen in an occlusal view, the cross-sectional geometry of the jaw in the midline, and the internal structure and physical properties of the bone. The comparative displacement of implants about the midline would be expected to be different where the interforaminal region of the mandible was relatively straight rather than markedly curved, as seen from the occlusal aspect. Similarly, internal shape and structure would influence functional deformation.

Hobkirk et al[10] suggested that mandibular deformation resulting from functional jaw movements should be accounted for in the design of mandibular implant-stabilized prostheses. They also questioned the validity of modeling techniques that do not allow for this phenomenon. The clinical significance of mandibular deformation is unknown, but it may be of relevance to implant treatment due to loosening of implant-supported superstructures caused by torque on screw joints; fracture of the metal superstructure and prosthesis screws due to the loads exerted on the prosthesis during mastication; and excessive loading of the implant-bone interface.

The clinical significance of mandibular deformation is unknown, and it could be argued that it is unimportant, because high success rates have been achieved with implant treatment without accounting for this phenomenon. It may, however, be of relevance when using implants in less favorable situations. In the absence of evidence to the contrary, it is important for the clinician to be aware of this phenomenon, which should be taken into consideration in the design and monitoring of mandibular prosthetic devices.

CONCLUSIONS

Nonmasticatory functional mandibular movements (ie, opening, lateral excursion, and protrusion) cause the mandible to deform in the midline. At least 3 types of distortion occur: medial convergence, corporal rotation, and anteroposterior shear. These 3 types of mandibular deformation occur concurrently. Anteroposterior shear can be measured in human subjects. In general, mandibular deformation was less during maximum lateral excursions than during maximum opening and maximum protrusion.

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