Condylar Paths during Protrusion in Edentulous Patients: Analysis with Electronic Axiography

Olivier Hüe, DDS, PhD

Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Denis Diderot University, Hôtel-Dieu, Garancière Dental Hospital, Paris, France

Keywords
Complete denture; articulators; temporomandibular joint; temporomandibular physiology; condylar movements; range of motion.

Correspondence
Olivier Hüe, Department of Prosthodontics, Faculty of Dentistry, Denis Diderot University, Hôtel-Dieu, Garancière Dental Hospital, 5 rue Garancière, 75006 Paris, France. E-mail: olivierjp3@wanadoo.fr

Accepted June 29, 2010

doi: 10.1111/j.1532-849X.2011.00715.x

Abstract

Purpose: The aim of this study was to determine the condylar form, incline, and movement characteristics during protrusive movement in fully edentulous complete denture wearers. The study went on to analyze the occlusal consequences on the setup of artificial posterior teeth and the occlusal grinding phase.
Materials and Methods: The study included 60 complete denture wearers (aged 58 to 74 years), who received a new set of complete dentures for this study. The patients did not present signs of muscular or articular pain. Protrusive movements were recorded by a SAM® electronic axiography system.
Results: Condylar paths exhibited fairly specific characteristics in the completely edentulous patients, particularly path forms, which had highly specific patterns. Three condylar path forms were determined: the classic form following a convex curve (41% of cases), a sinusoidal form that flattened out in the first 2 mm before following a convex curve (51%), and a rectilinear path (9%). The mean condylar angles also exhibited specific patterns. The mean started in the first millimeter of protrusive movement, at $32.2^\circ \pm 14.9^\circ$, and then increased in the second millimeter to $40.4^\circ \pm 11.9^\circ$, reaching $44.5^\circ \pm 9^\circ$ at 5 mm.
Conclusion: During protrusive movement in completely edentulous patients, the condylar path patterns were different than conventionally described patterns. In particular, the sinusoidal form was frequently found, and the incline of the condylar slope was low. These factors need to be taken into account during the final occlusal selective grinding for new sets of complete dentures.

Condylar paths during protrusion have been extensively studied as clues to understanding and reproducing mandible movement patterns with articulators.[1] Many authors have led this research by exploiting a broad panel of techniques, ranging from photography to intraoral wax records and graphic or functional analysis recordings.[2-6] This panel of analytical techniques made it possible to determine the characteristic forms and inclines of condylar pathways.[7-9] However, all of these methods remain limited in terms of the possibilities for analyzing and interpreting results, because they deliver essentially visual datasets that are only partially complete and rarely perfectly quantified.[10-11]

These characteristics are considered to be definitive and reproducible throughout life, because the temporomandibular joints (TMJs) are considered fixed and stable structures.[12] However, like any skeletal bone structure, TMJs evolve over time. The temporal and condylar processes are progressively remodeled and reshaped, not just with age, but also with edentulism and internal derangements.[13-17] These form shifts then influence the characteristics recorded at the extension limits of the mandibular movements.[18-20] However, studies have been unable to quantify these form changes.

Axiography, a graphical recording technique, has been able to compensate for these shortfalls.[21-23] Electronic axiography was further developed by the Axiocomp® system (SAM Präzisionstechnik, Gauting, Germany), making it possible to record condylar paths with accuracy and to deliver high-precision numerical data on these movements.[24-26] These numerical data permit users to know the exact condylar influence on the occlusal morphology of the posterior teeth in occlusal schemes, such as a balanced occlusion.[27-35]

The aim of this study was to determine the characteristic forms and condylar path inclines during protrusive movement in edentulous patients, using Axiocomp® (SAM), as key inputs to properly adjust an articulator, as well as to evaluate the impact of these characteristics on the occlusal morphology of prosthetic teeth.

Journal of Prosthodontics **20** (2011) 294–298

Materials and methods

Patients

The study included 60 wearers of removable complete dentures (34 women and 26 men, aged 58 to 74 years, mean age 69 ± 2.4 years). Inclusion criteria for this study were replacement of the dentures with a new set of removable complete dentures and an absence of articular or muscular pain during palpation. Two months after delivering the new set of dentures and completing the various occlusion and denture-base-related adjustments, the condylar paths were recorded during protrusive movement.

This study was conducted in full compliance with the rules set out in the local public health code. All patients were informed in detail of the aim of the study and the methods employed, and all patients signed an informed consent form.

Computerized axiography

Protrusive movements were recorded using the electronic axiography system developed by H. Mack. The system comprised:

1. The SAM Axiograph® system consisting of a conventional double facebow attached to the patient. The maxillary and mandibular bows were both equally tightened and bulky.[34] The mandibular bow is used to transmit the movements of the hinge axis to the maxillary facebow. The mandibular bow can be adjusted in two dimensions, making it possible to kinematically localize the hinge axis.
2. An Axiotron® consisting of two digitizer flags and two electronic sensors connected to a PC. The digitizer flags are set to the maxillary facebow in the condylar region and oriented in the parasagittal plane to register hinge axis movements in the sagittal plane. The sensors at the tips of the mandibular bow arms register the movements of the hinge axis in the frontal plane.
3. Axiocomp® software system for PC, which receives and processes the data from the digitizer flags and electronic sensors.

Measurements

First, recording denture bases were made using the "sprinkle-on" technique with the duplicate secondary impression casts. The casts were mounted on a SAM II articulator using a facebow and centric relation record. A central bearing point was set on the recording bases to record protrusive movements via gentle, controlled guidance without variation in the vertical dimension. The incisal pin of the articulator was precalibrated to hold the occlusal vertical dimension while setting the central bearing point. The stylus of the central bearing point was placed in the middle of the mandibular recording base, and the concave plate of the central bearing was placed up against it at the maxillary recording base as previously described in a study on recording border movement ranges.[19]

Second, the mandibular recording base was set on the mandibular arch and held in place with a mandibular clamp. To prevent any pain during the procedure, the mucosal surface of the mandibular recording base was coated in analgesic cream (Xylocontact crème®; Pierre Rolland, Bordeaux, France). The maxillary facebow was held in place at the front using a nasal index braced at the depression of the nasal bridge and at the back with a pericranial elastic strap. The mandibular bow was locked onto the mandibular clamp support rod. The digitizer flags were fitted into the maxillary side arms, and the electronic sensors were fitted onto the tips of the lateral arms of the mandibular bow (Fig 1). The kinematic hinge axis was localized by coupling the sensors and the flags to the software.[36] The mandible was placed in the posterior reference position using nonforced chin guidance. The axio-orbital plane was determined as the reference plane with the anterior point marking the lower part of the orbital margin.

Third, the patient was guided through a series of protrusive movements while maintaining contact between the concave plate and the stylus of the central bearing point. Three protrusive movements were recorded with the patient sitting upright and with his/her head set gently against the headrest. The starting point for the protrusive movements was the

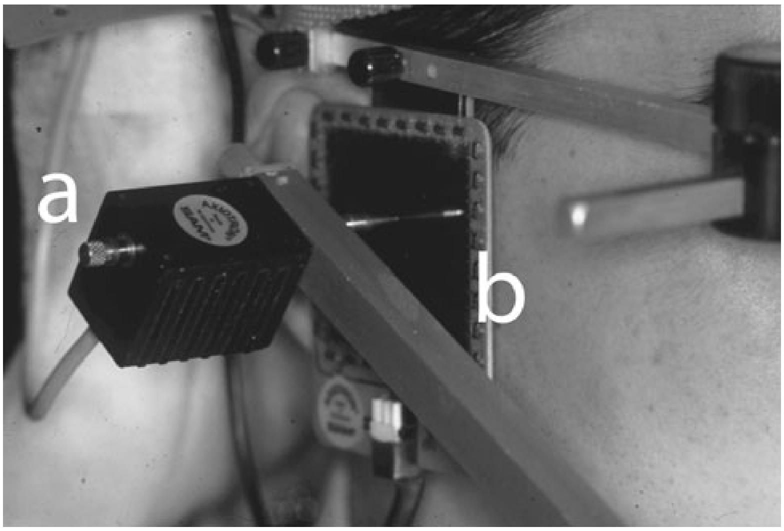

Figure 1 Overview of the recording system: (a) electronic sensor fitted onto the lateral arm of mandibular bow, (b) digitizer grid fitted onto the lateral arm of the upper facebow.

reference condylar position, and the movements were performed free of any guidance. The longest recording was analyzed in all three recording series, in compliance with the criteria used by Gsellmann et al.[26]

Statistical analysis

Data were analyzed using SPSS® (ver. 11.5; SPSS Inc., Chicago, IL) software. For protrusive movement, the distribution of the condylar pathways was compared between the right and left sides using Pearson's chi-square test. The relationship between the condylar angle and shift in protrusive movement was tested by Pearson's correlation ($\alpha = 0.05$).

Results

Protrusions were assessed on the right (n = 60) and left (n = 60) to characterize the condylar paths.

Form

Three form groups were identified for the condylar paths: (1) convex path; (2) a sinusoidal path with slight concavity at the start of the path followed by a convex movement; (3) a rectilinear form (Table 1). Pearson's chi-square tests showed no significant difference in the distribution of the path form between the right and left sides ($p = 0.15$).

Incline

In the first millimeter of protrusion, the average condylar angle was a relatively low 32.2°. The angle jumped to 40.4° at the second millimeter, and reached 44.5° at 5 mm (Table 2). The condylar angle was significantly positively correlated to protrusive extension ($\rho = 0.81$; $p < 0.01$).

Discussion

Axiography

Many dental practitioners consider this system to be a reliable technique for registering condylar movement when applied to the analysis of condylar kinematics and articulator-reproduced recorded positions.[19] In this study, electronic axiography was applied solely for this objective. However, Kenworthy et al[35] reported that the weight of the apparatus combined with the positioning of the recording systems outside the condylar poles can be a source of inaccuracy, though they also added that using the same parameters across all measurements on different patients makes it possible to run comparisons.

Table 1 Numbers and percentages of different condylar path forms

Form	Right	Left	Total	%
Convex	27	20	47	40
Sinusoid	25	37	62	51
Straight	7	4	11	9

Table 2 Mean angulations and standard deviation of the condylar angles

Protrusion	Number	Average angle	SD
1 mm	120	32.2°	14.9°
2 mm	120	40.4°	11.9°
3 mm	120	42.8°	11°
4 mm	115	44.8°	9°
5 mm	112	44.5°	9°
6 mm	110	43.9°	9°

Form

Forty percent of the edentulous patients presented with a protrusive movement pattern following the same form as the convex path normally described. Studies in dentate patients have only identified this form in between 67%[24] and 75% of records.[16]

The sinusoidal path was the most frequent path in this study (51%). This path differs radically from the classical paths, but other studies reported this path in 27%[24] and 8%[16] of cases. In contrast, this form was never identified by Lundeen et al[19] in their study using the Lee air turbine engraving system,[21] which is based on the same recording principle as axiography.

This sinusoidal shape can be interpreted via two hypotheses:

1. *Tipping of the condylar head:* This hypothesis stems from the use of the central bearing point and was proposed by Boucher and Jacoby.[10] The authors assert that this device pushes the condyles to tip back distal-inferiorly from the central[OH1] relation; however, both Piehslinger et al[25] and Merlini and Palla[16] highlighted this flattening out, despite the fact that their studies did not use the central bearing point. Furthermore, Lundeen et al[17] used a central bearing point without finding any evidence of this sinusoidal pattern.
2. *Altered disk-condyle relations:* This flattening out flags an altered condyle-disk unity according to Slavicek's criteria for interpreting axiographic tracings.[22] The alteration is purported to stem from a drop in ligament stability and changes in articular structure following partial, and then total, tooth loss.[17] However, it should be noted that the diagnostic value of axiographic recordings in TMJ disorders is, like all tracking device-based protocols, hotly contested.[11]

A rectilinear path was identified in 9% of patients, higher than the 2% to 3% reported by Piehslinger et al.[25] The rectilinear form represents an alteration in the bone morphology of the articular structures, causing a flattening out of the condylar and coronoid processes. These alterations are connected to the impact of tooth loss on articular morphology.[8,23–24]

Incline

In the first millimeter of protrusion, the average condylar angle (32.2°) in relation to the axio-orbital plane was far lower in these completely edentulous patients than in the dentate patients studied by Slavicek[22] (53°), Lundeen et al[19] (51.3°), and

Wirth[20] (49.4°); however, the average value at 5 mm (44.8°) was close to the values reported by Lundeen et al[19] (44.5°) and Slavicek[22] (47.3°), though drifting slightly from Posselt and Nevstedt[6] (40°). Both Aull[7] and Isaacson[8] obtained different figures using $2\frac{1}{4}$-inch curvilinear inserts as the top wall of the condylar houses (Stuart articulator); however, these results can only be cross-compared with caution because some uncertainty exists regarding the choice of the reference plane. In most cases, the axio-orbital plane was used. Posteriorly, the reference point can be determined either kinematically, as demonstrated by Slavicek[22] and Piehslinger et al,[25] or arbitrarily. Anteriorly, there are five individual reference points: *orbital point*, *orbital point minus 7 mm*, *nasion minus 23 mm*, *incisal edge*, and *alae of the nose*.[28] In Posselt's research,[6] the reference plane was the Frankfort horizontal plane, which differs from the axio-orbital plane.

Occlusal impact

The above results need to be realigned to the aim of our study, which was to determine condylar paths and angles and reproduce them on articulators to establish a bilaterally balanced occlusal scheme. Geometric analysis revealed that the condylar slope, incisal table angle, and cuspal inclination were directly co-related. This relationship was first established by Hanau[5] via his "Quint" in 1926 before being reformulated by C.O. Boucher.[27] Since that time, numerous techniques have been proposed for assessing the resulting impact, including the cusp writer (Scott[28]), the mechanical plotter (Lundeen[23]), and computer-graphic representation (Roedema[29]), in addition to various mathematical equations.[10,25,31,32] Wagner and Rennels[31] determined cusp inclines at the cusp of the maxillary first molar according to condylar slope settings on a Hanau 96H2 articulator (Whip Mix Corporation, Fort Collins, CO). The obtained cusp angles made it possible to calculate the specific height of the cusp inclines (Fig 2).

Table 3 Cuspal heights related to the horizontal plane, according to condylar angle

Condylar angle	Incisal table angle	Cusp inclines to horizontal to horizontal plane	Cuspal heights to horizontal plane
30°	0°	15.4°	0.26 mm
40°	0°	20.5°	0.35 mm
50°	0°	25.5°	0.43 mm

The calculations suggested that at the mesial cusp of the upper first molar, if the angulation of the condylar slope is established at 30°, the cuspal height would be 0.26 mm to the horizontal plane. Consequently, the cuspal height would be 0.35 mm for 40° and 0.43 mm for 50° (Table 3), meaning that the difference between the cuspal heights could reach 0.17 mm when condylar slopes vary from 30° to 50°. The condylar inclination of 50° is obtained when using a condylar house with a curvilinear upper wall, such as the Whip Mix® 2000 series (Whip Mix, Louisville, KY).

In functional practice, this occlusal discrepancy could result in discomfort, instability of the denture base, mucosal irritation, and a loss of jaw muscle power. Exteroceptors in contact with the denture base actually help in mandibular position perception.[33] Furthermore, during mastication, over 85% of occlusal contacts occur within a broad 0.2 to 1.2 mm zone around the maximal intercuspal position.[34] This zone matches the dimensional area within which the condylar angle has the greatest effect on occlusal morphology. To meet both geometric and functional objectives, the correction of occlusal discrepancies should always be performed on an articulator with adapted settings.[35]

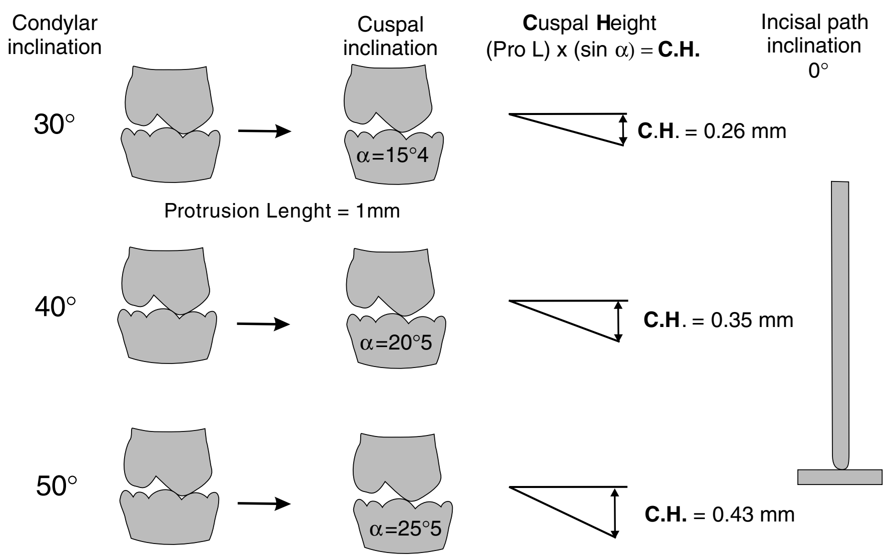

Figure 2 Cuspal heights in accordance with variations in condylar inclination at 1 mm of protrusion. Values obtained from Wagner and Rennels.[30]

Conclusion

This study demonstrates that condylar path form and incline are significantly different from conventionally described paths. Patient age and edentulous status greatly influence the characteristics of condylar paths during protrusion. The sinusoidal form condylar path was most frequently found, and the condylar slope incline was low during the first millimeter of protrusive movement. In complete denture wearers, these characteristics have a direct impact on the occlusal morphology of the posterior teeth and need to be taken into account by dental practitioners during the final occlusal selective grinding phase.

Acknowledgment

The author thanks Paul Kretchner for editing and improving the presentation of this manuscript.

References

1. LePera F: Undestanding graphic records of mandibular movements. J Prosthet Dent 1967;18:417-424
2. Campion G: Some graphics records of movements of the mandible in living subjects and their bearing on the mecanism of the joint and the construction of articulators. Dent Cosmos 1905;47:39-45
3. Gysi A: The problem of articulation. Dent Cosmos 1910;52:403-413
4. McCollum BB, Stuart CE: A Reseach Report. Chas. F. Stuart P.O. Box 1298 Ventura, CA 930010
5. Hanau R: Articulation defined, analyzed and formulated. J Am Dent Assoc 1926;16:1694-1707
6. Posselt U, Nevstedt P: Registration of the condyle path-inclination by intraoral wax records; its practical value. J Prosthet Dent 1960;11:43-47
7. Aull AE: Condylar determinants of occlusal patterns. Part I. Statistical report on condylar path variations. J Prosthet Dent 1965;15:826-849
8. Issaacson DA: A clinical study of the condylar path. J Prosthet Dent 1959;9:927-935
9. Wilkie ND: The anterior point of reference. J Prosthet Dent 1979;41:488-496
10. Boucher LJ, Jacoby J: Posterior border movements of the mandible. J Prosthet Dent 1961;11:836-841
11. Mohl ND, McCall WD Jr, Lund JP, et al: Devices for the diagnosis and treatment of temporomandibular disorders. Part I: Introduction, scientific evidence, and jaw tracking. J Prosthet Dent 1990;63:198-201
12. Lucia V: Modern Gnathological Concepts. St Louis, Mosby, 1961
13. Blackwood HJJ: Histological aspects of remodeling activity in the temporomandibular joint. In Schwartz L, Chayes CM (eds): Facial Pain and Mandibular Dysfunction. Philadelphia, Saunders, 1969, pp. 69-82
14. Carlsson GE, Kopp S, Öberg T: Arthritis and allied diseases of the temporomandibular joint, in temporomandibular joint function and dysfunction. In Zarb GA, Carlsson GE (eds): Temporo-Mandibular Joint Function and Dysfunction. Copenhagen, Munksgaard, 1979, pp. 269-320
15. Mongini F: Anatomic and clinical evaluation of the relationship between the temporomandibular joint and occlusion. J Prosthet Dent 1977;38:539-551
16. Merlini L, Palla S: The relationship between condylar rotation and anterior translation in healthy and clicking temporomandibular joints. Schweiz Monatsschr Zahnmed 1988;98:1191-1199
17. Matsumoto A, Celar RM, Celar A, et al: An analysis of hinge axis translation and rotation during opening and closing in dentulous and edentulous subjects. Cranio 1995;13:238-241
18. Mongini F: Relationship between the structures of temporomandibular joint and pantographic tracings of mandibular movements. J Proshet Dent 1980;43:331-337
19. Lundeen HC, Shryock EF, Gibbs CH: An evaluation of mandibular border movements: their character and significance. J Prosthet Dent 1978;40:442-452
20. Wirth CG: Recording condylar movement. Angle Orthod 1997;67:87-90
21. Lee R: Jaw movements engraved in solid plastic for articular controls. Recording apparatus. J Prosthet Dent 1969;22:209-224
22. Slavicek R: Clinical and instrumental functional analysis for diagnosis and treatmentplanning. Part 5. Axiography. J Clin Orthod 1988;22:656-672
23. Lundeen HC, Wirth CG: Condylar movement patterns engraved in plastic blocks. J Prosthet Dent 1973;30:866-875
24. Piehslinger E, Celar AG, Celar RM, et al: Computerized axiography: principles and methods. Cranio 1991;9:344-355
25. Piehslinger E, Celar A, Futter K, et al: Orthopedic jaw movement observations. Part I: Determination and analysis of the length of protrusion. Cranio 1993;11:113-117
26. Gsellmann B, Schmid-Schwap M, Piehslinger E, et al: Lengths of condylar pathways measured with computerized axiography (CADIAX) and occlusal index in patients and volunteers. J Oral Rehabil 1998;25:146-152
27. Boucher CO: Swenson's Complete Dentures (ed 6). St Louis, Mosby, 1970, pp. 140-145
28. Scott WR: Application of "cusp writer" findings to practical and theorical occlusal problems. J Prosthet Dent 1976;35:332-340
29. Roedema WH: Computer-graphic representation of mandibular movements in three dimensions. Part II: The sagittal and frontal planes. J Prosthet Dent 1978;40:385-391
30. Morita O, Miyagawa Y, Lang BR: Determining the pathway of protrusive movement on arcon and nonarcon articulators by mathematical equation. J Prosthet Dent 1982;47:330-335
31. Wagner AG, Rennels KE: The effect of the articulator settings on the cusp inclines as measured by a coordinate measuring machine. J Prosthodont 1993;2:19-23
32. Munakata Y, Kasai S: Contribution of the mucosal tactile information to the mandibular position sense in patients wearing dentures. J Oral Rehabil 1992;19:649-654
33. Kumagai H, Watanabe T, Kobayashi K, et al: Incidence of occlusal contacts with complete dentures during mastication using a 6-channel telemetry system: preliminary measurements. J Oral Rehabil 1999;26:918-922
34. Shigli K, Angadi GS, Hegde P: The effect of remount procedures on patient comfort for complete denture treatment. J Prosthet Dent 2008;99:66-72
35. Kenworthy CR, Morrish RB Jr, Mohn C, et al: Bilateral condylar movement patterns in adult subjects. J Orofac Pain 1997;11:328-336
36. Bernhardt O, Küppers N, Rosin M, et al: Comparative tests of arbitrary and kinematic transverse horizontal axis recordings of mandibular movements. J Prosthet Dent 2003;89:175-179