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Clinical Paper
TMJ Disorders

Alterations of mandibular movement patterns after total joint replacement: a case series of long-term outcomes in patients with total alloplastic temporomandibular joint reconstructions

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Abstract. According to recognized guidelines, a total alloplastic replacement may be indicated to resolve temporomandibular pain and functional limitations in cases where conservative and less aggressive surgical management strategies have failed. It is broadly believed that, as a result of the surgical procedure, the function of the lateral pterygoid muscle is lost and so are the laterotrusive and protrusive jaw movements. Furthermore, the joint prosthesis design may not be conducive to lateral and protrusive movements. Using a dynamic stereometry technique, it was possible to perform a quantitative analysis of kinematics in TJR patients. The cases of four patients who showed preserved lateral and/or protrusive motion are presented here. During mouth opening, prosthetic condyle translation ranged from 3.18 mm to 10.09 mm and it was also possible to observe this clinically. It has been suggested that changes in prosthesis design may have improved postoperative jaw kinematics. Considering the large diversity in treatment outcomes, it is recommended that the individual prognosis should always be discussed with the patient prior to surgery.

Key words: temporomandibular joint; joint replacement; arthroplasty; biomechanics; mandibular motion.

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Despite the high prevalence of temporomandibular disorders (TMDs)[1], the indication for surgical treatment, and especially for joint replacement, is rare[2,3]. TMDs can most often be managed successfully using non-invasive therapies such as self-management training, physiotherapy, occlusal splints, and non-steroidal anti-inflammatory drugs[4,5]. Nevertheless, there are cases in which conventional measures fail and invasive procedures are needed. In cases of so-called end-stage pathologies, alloplastic total joint replacement (TJR) should be considered[6–9].

There are several indications for TJR, such as congenital joint deformity, a history of tumour-related joint resection, ankylosis or re-ankylosis, failed post-traumatic osteosynthesis, degenerative diseases (e.g., severe osteoarthritis, inflammatory osteoarthritis, autoimmune disease), idiopathic resorption, and failed autogenous grafts[10–12]. Although the body of literature on clinical and subjective outcomes of TJR has been growing lately, few studies have investigated TJR function. Additionally, reported objective outcomes have mostly been limited to simple measurements such as inter-incisal opening, and comprehensive kinematic analysis has not been reported[13–16].

This article presents the clinical and biomechanical outcomes of four patients after TJR, who exhibited remarkable kinematic features. An example of a healthy subject with no TMD signs or symptoms is also presented. It is believed that sharing this information with a broad group of clinicians will contribute to a better understanding of the multidimensional alteration of patient biomechanics after TJR surgery.

Methods

A subset of TJR patients together with a control subject free of signs or symptoms of TMD, who were recruited for a previous study[17], underwent a re-evaluation involving individual motion analysis of the mandible. Movement data were obtained by means of dynamic stereometry. This technique allows the precise acquisition of mandibular kinematics and permits qualitative and quantitative analyses. Dynamic stereometry was invented over 20 years ago in the authors' research laboratory and has undergone continuous development ever since[18,19]. It combines the patient's anatomy with their individual movement pattern, thus providing an in vivo insight into temporomandibular joint (TMJ) biomechanics. Anatomical data can be obtained by means of any three-dimensional imaging technique, e.g., magnetic resonance imaging (MRI) or digital volume tomography (DVT).

In this study, each patient's anatomy was obtained by means of DVT (KaVo 3D eXam 1; KaVo GmbH, Leutkirch, Germany). The control subject's anatomy was obtained by MRI (Siemens Healthcare, Erlangen, Germany) in order not to expose the subject to unnecessary radiation. Thereafter the jaw movement was recorded by three linear cameras with a sampling frequency of 200 Hz and geometrical resolution better than 5 μm. A common reference system enabled animation of the virtual osseous anatomy with jaw tracking data via continuous co-ordinate transformations. As a final result, the vectors of the displacement of the condylar centres during mouth opening, protrusion, and laterotrusion were determined. Additionally measurements of the inter-incisal point (IP) shift were performed for the same movements using a conventional ruler. Each movement was repeated three times and descriptive statistics were calculated.

This study was performed in accordance with the Declaration of Helsinki on medical protocol and ethics and was approved by the local ethics committee. Written informed consent was obtained from all participants.

Results

The clinical measurements of all patients and the control subject are summarized in Table 1. The biomechanical outcomes are described in Table 2.

Patient 1

A 22-year-old female presented with limited mouth opening and constant pain in the right TMJ area[20]. Clinical and radiological examinations revealed a suspect mass in the painful area. The patient underwent a condylectomy and the histological examination revealed pigmented villonodular synovitis (PVNS). The condyle was temporarily replaced with a 2.4-mm reconstruction plate (Synthes AG, Oberdorf, Switzerland) as a space-holder for later TMJ reconstruction. One and half years later, a TJR was performed with a custom-fitted TMJ Concepts TMJ prosthesis (TMJ Concepts Inc., Ventura, CA, USA). At the 9-year follow-up after TJR, her occlusion was stable. For the clinical measurements of IP movement, please see Table 1. During opening, the IP initially deviated from the midline to the right, and then returned to the midline at the end of the movement (Fig. 1). The radiological follow-up showed no heterotopic bone formation and no recurrence of PVNS-associated lesions.

Dynamic stereometry revealed that at mouth opening, the alloplastic joint moved 6 mm from its original position. During clinical examinations, the patient's ability to perform a laterotrusion of 5 mm to the left, i.e. contralateral to the artificial joint, was an unexpected finding (Fig. 2). Dynamic stereometry showed that the left natural TMJ moved dorsally and cranially in a greater range than the alloplastic joint, thus providing a lateral shift of the IP.

Patient 2

A 61-year-old female, referred by a rheumatologist, presented with an occlusal disturbance (open bite on the left), mouth opening deviation to the right, crepitus in the right TMJ, and pain in both joints. Her mouth opening was not limited and measured 40 mm. She had a 10-year history of rheumatoid polyarthritis (rheumatoid factor (RF)-negative, anti-citrullinated protein antibody (ACPA)-positive, anti-cyclic citrullinated peptide antibody (anti-CPP)-positive, anti-nuclear antibody (ANA)-positive). On the cast models, the occlusion could be corrected as no tooth movement had occurred. After the diagnosis of bilateral TMJ rheumatoid arthritis had been confirmed radiologically, the decision was made to perform an alloplastic replacement of the more severely damaged TMJ. She received a stock Biomet Microfixation TMJ Replacement System (Biomet Microfixation, Jacksonville, FL, USA) on the right side. After 16 months, the patient returned with new

Table 1. Clinical measurements of the inter-incisal point (IP) shift (in millimetres).

	TJR side	Opening pattern	Opening	Protrusion	Laterotrusion	
					Right	Left
Patient 1	Right	Corrected	55	5	11	5
Patient 2	Bilateral	Straight	42	0	2	4
Patient 3	Right	Uncorrected	33	0	0	1
Patient 4	Left	Uncorrected	57	2	4	7
Control	NA	Straight	49	7	9	10

TJR, alloplastic total joint replacement; NA, not applicable.

Table 2. Results of the dynamic stereometry of the centres of the condyles: *x* increasing anteriorly, *y* cranially, and *z* to the patient's right side; *l* is the overall shift of the condyle centre. All measurements are in millimetres.

	Patient 1							
	TMJ right (prosthetic)				TMJ left			
	x	*y*	*z*	*l*	*x*	*y*	*z*	*l*
Opening	1.41	−5.82	−0.17	6.00	25.85	−6.49	0.33	26.66
Protrusion	2.68	−0.94	0.63	2.92	11.77	−6.55	−0.03	13.48
Laterotrusion right	1.97	−1.05	1.67	2.80	11.36	−6.65	0.95	13.18
Laterotrusion left	0.12	−0.33	−1.82	1.87	−2.23	1.60	−1.23	3.04
	Patient 2							
	TMJ right (prosthetic)				TMJ left (prosthetic)			
	x	*y*	*z*	*l*	*x*	*y*	*z*	*l*
Opening	6.77	−3.86	−0.23	7.80	5.77	−4.28	−0.20	7.20
Protrusion	0.68	0.10	−0.48	0.85	0.38	−0.30	−0.45	0.68
Laterotrusion right	0.17	−0.19	0.71	0.76	0.72	−0.22	0.63	0.97
Laterotrusion left	0.39	0.00	−1.02	1.10	−1.26	−0.19	−0.88	1.57
	Patient 3							
	TMJ right (prosthetic)				TMJ left			
	x	*y*	*z*	*l*	*x*	*y*	*z*	*l*
Opening	2.77	−1.38	−0.72	3.18	1.93	−3.08	−0.89	3.74
Protrusion	0.36	−0.06	0.14	0.41	−0.06	0.01	0.16	0.38
Laterotrusion right	−0.06	0.16	0.06	0.46	0.23	0.16	0.04	0.59
Laterotrusion left	0.95	−0.13	−0.25	0.99	−0.18	0.07	−0.11	0.42
	Patient 4							
	TMJ right				TMJ left (prosthetic)			
	x	*y*	*z*	*l*	*x*	*y*	*z*	*l*
Opening	18.91	−8.34	−0.26	20.68	5.91	−8.15	−0.56	10.09
Protrusion	6.52	−3.03	1.49	7.42	−0.93	0.47	1.43	1.92
Laterotrusion right	0.83	−0.29	2.79	2.94	−0.54	−1.24	2.78	3.20
Laterotrusion left	6.66	−3.58	−0.05	7.60	0.64	−0.27	−1.82	2.26
	Control							
	TMJ right				TMJ left			
	x	*y*	*z*	*l*	*x*	*y*	*z*	*l*
Opening	13.59	−4.59	−1.31	14.41	14.13	−5.98	−1.38	15.41
Protrusion	6.53	−3.15	0.23	7.25	5.93	−3.30	0.27	6.79
Laterotrusion right	1.21	−0.70	−0.30	1.43	6.03	−4.12	0.39	7.32
Laterotrusion left	10.39	−4.77	−1.15	11.49	1.79	−1.20	−0.02	2.23

TMJ, temporomandibular joint.

symptoms in the left TMJ. The joint was painful and there was a premature occlusal contact on the left premolars. A TJR with the same system was performed on the left side.

At the 5-year follow-up, her occlusion was stable and she experienced only episodic slight pain on the left side. As a late complication she reported symptoms of Frey syndrome. Her mouth opening was 42 mm (see Table 1). Although protrusive movements were impossible, laterotrusion to the right and to the left measured 2 mm and 4 mm, respectively (Fig. 3). As shown by dynamic stereometry, both condyles shifted to the ipsilateral side during laterotrusion. Furthermore, during the movement to the right, both condyles shifted ventrocaudally. When performing the left side movement, the left condyle moved dorsocranially, thus resulting in a wider range of motion to the left than to the right.

Patient 3

A 44-year-old female presented with a fracture of the right condyle after a horse riding accident. Primary non-surgical fracture management failed and the decision to insert an osteosynthesis plate was taken after 4 months. As a result, normal TMJ function was restored. Unfortunately, only 5 months later, the patient experienced a new accident. She then presented with a frontal and left open bite, crepitus, pain, and no translational movement in the right TMJ. Computed tomography revealed a dislocated condylar head fracture and callus formation between the fragments in the right TMJ. Since the displaced fragments could not be stabilized successfully with a conventional osteosynthesis plate, the right TMJ was then reconstructed with a Biomet Microfixation TMJ Replacement System implant.

At the 4.5-year follow-up, she appeared with no pain and with a stable occlusion. MRI revealed heterogeneous tissue around the left TMJ, suggesting mixed fibro-osseous ankylosis of the joint. The patient was informed about the finding and possible therapy. Since the patient was not experiencing any pain in the left TMJ, she did not wish to

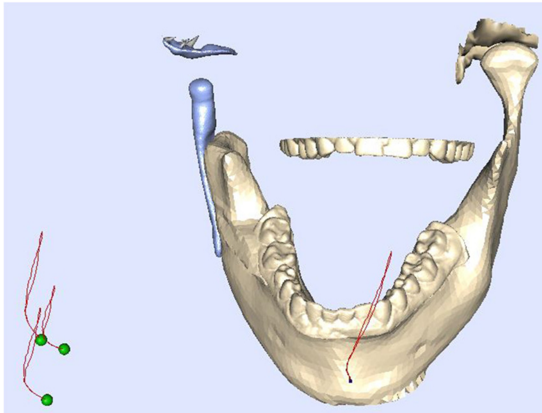

Fig. 1. Trajectory of the mental point during the opening movement of patient 1. The corrected deviation of the midline can be observed. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

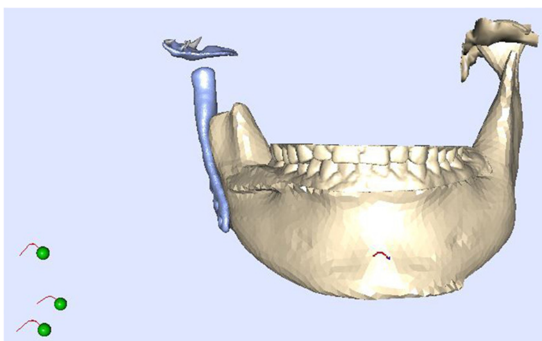

Fig. 2. Trajectory of the mental point during the laterotrusive movement contralateral to the prosthetic joint of patient 1. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

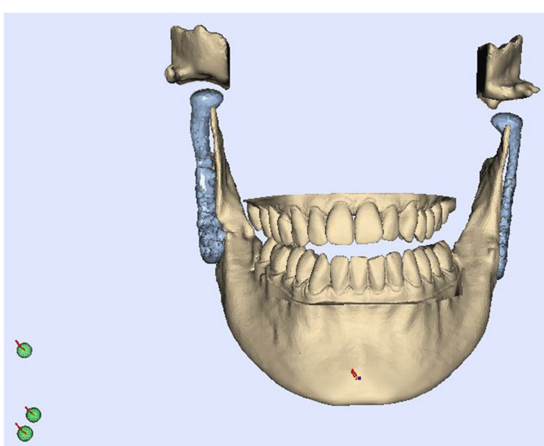

Fig. 3. Trajectory of the mental point during the laterotrusive movement to the left of patient 2. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

undergo surgical treatment and has remained under regular observation.

Clinically, her mouth opening measured 33 mm and deviated slightly to the left (approximately 2 mm) (Fig. 4). Protrusion and laterotrusion to the right were impossible and laterotrusion to the left measured 1 mm. Dynamic stereometry showed a clear laterotrusive movement, albeit small, of the alloplastic replacement towards the ankylotic natural joint.

Patient 4

A 48-year-old male presented after a motorcycle accident with multiple contusions, limited mouth opening, occlusal disturbance, and swelling and pain in the left TMJ area. Clinical and radiological examinations revealed a left TMJ neck fracture. The decision was made to perform open fracture treatment. After the healing phase, the patient continued to experience persistent pain in the pre-auricular area on the operated side, as well as an occlusal disturbance. A radiological examination revealed degenerative changes, exostoses, and subchondral sclerosis, and the patient underwent a surgical revision. A loose distal fragment was removed and the condyle was replaced with a condylar head add-on system (DePuy Synthes, West Chester, PA, USA) as a temporary space holder. Five years later, he presented again with pain, swelling, and limited mouth opening. The prosthetic condylar head was displaced into the skull base and was tightly surrounded by bone. Rigid fixation of the prosthesis in the osseous structures had caused a material failure resulting in a plate fracture. The broken plate was removed and a custom-fitted TMJ Concepts TMJ prosthesis (TMJ Concepts Inc., Ventura, CA, USA) was inserted.

At the 9-year follow-up after TJR, his occlusion was stable. Mouth opening and chewing function were unlimited. The radiological follow-up showed no heterotopic bone formation. For the clinical measurements of IP movement, please refer to Table 1.

Dynamic stereometry revealed that during mouth opening, the alloplastic joint moved 10 mm from its original position (Fig. 5). Clinically, a laterotrusion of 4 mm to the right, i.e. contralateral to the artificial joint, was observed (Fig. 6). Dynamic stereometry showed that both TMJs moved almost 3 mm to the right, thus providing a lateral shift of the IP.

Control subject

As an example of healthy TMJ kinematics, the data of a 55-year-old female with no history of TMD signs or symptoms is also presented in Tables 1 and 2. Figure 7 shows a visualization of the movement patterns.

Discussion

The analysis of patient 1 revealed a mainly dorsoventral shift of the natural condyle

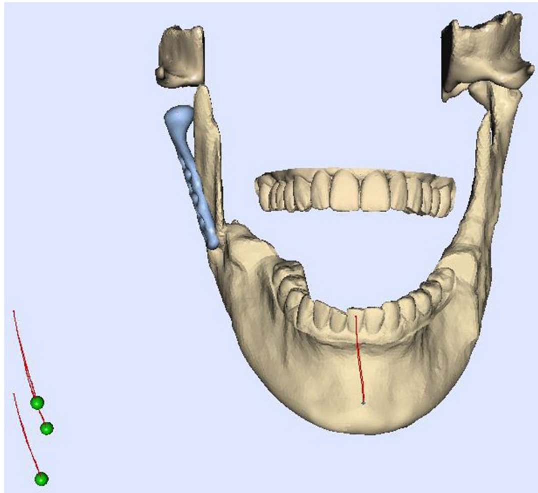

Fig. 4. Trajectory of the mental point during the opening movement of patient 3. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

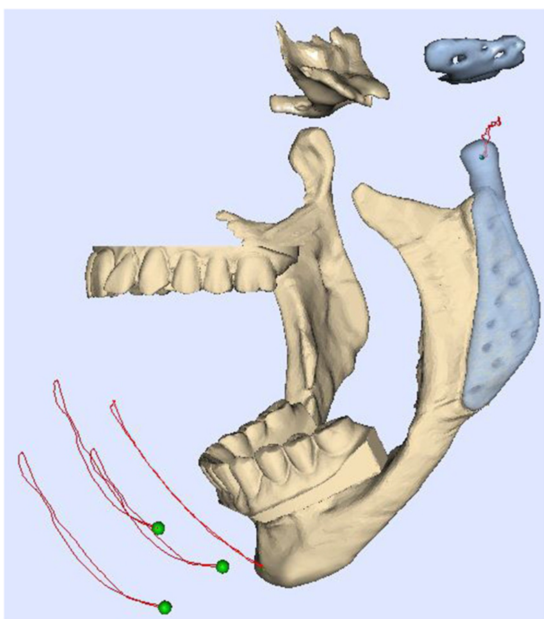

Fig. 5. Trajectory of the mental point as well as the centre of the prosthetic condyle during the opening movement of patient 4. Translation of the alloplastic joint is presented. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

during mouth opening, clearly exceeding the values of healthy controls as reported previously[17] (26.66 mm vs. 9.01 ± 3.8 mm for the controls). Furthermore, this case showed a clear laterotrusive movement to both sides. Peculiarly, during laterotrusion to the left, the ipsilateral natural condyle shifted dorsally and cranially, thus pulling the contralateral alloplastic joint medially. Physiologically, the retrusive movement does not exceed 2 mm[21], but in this case the condylar centre shifted by more than 3 mm. The enhanced mobility of the natural condyle in all directions may suggest loosening/stretching of the joint capsule as well as its ligaments. The patient reported performing an intensive physiotherapy routine for 6 months postoperatively, in addition to daily mouth-opening self-management training.

In patient 2, a significant shift in ventrocaudal direction of both alloplastic condyles was observed. Additionally, during laterotrusion to the left, a shift in dorsolateral direction occurred in the ipsilateral joint. Despite the limited range of mandibular motion, patient 3 showed a slight gliding movement in both the alloplastic and the natural joint. Surprisingly, the alloplastic condyle moved further ventrally during mouth opening, which corresponded to the unexpected chin deviation towards the natural side observed clinically.

Patient 4 is an example of successful trauma management after multiple failed surgeries. Even after years of limited range of motion, condylar translation could be restored.

Relative to the head, the natural TMJ has 6 degrees of freedom and its movement during jaw opening/closing is usually described as a combination of condylar rotation and translation[22,23]. It is widely believed that the main muscle accountable for the translational component is the lateral pterygoid. The surgical procedure of alloplastic TMJ replacement requires the excision of the mandibular condyle by cutting it at the level of the mandibular notch. As an inevitable result, the insertion of the lateral pterygoid muscle on the condylar neck is disconnected. The loss of lateral pterygoid function is the most broadly discussed reason for the absence of condylar translation and the resulting restricted and/or deviated range of motion[16,24].

Nevertheless, experimental studies have shown that even if muscular function is fully restored, the spherical fossa form of currently available TJR systems would not allow translational movements[25–27]. For this reason, attempts have been made to adapt the fossa shape to physiological jaw kinematics. In the new Melbourne TJR system, the fossa is shaped to facilitate translation and is equipped with anterior and posterior flanges preventing joint dislocation[28]. Future studies should determine whether this solution improves the opening range of motion. Other authors have suggested that an excessive scar formation process could vastly limit jaw mobility after TJR[29]. Indeed, a tense fibrous pseudocapsule has been found clinically and histologically after TJR revision surgeries. To prevent scar formation and especially heterotopic calcification, fat is often packed around the condyle; however, the authors are unaware of any randomized controlled trial that has verified the efficacy of this practice[30,31].

In patients 1, 2, and 4, a surprising gliding movement was observed, despite the absence of lateral pterygoid attachment, whereas preoperatively only patient 2 had a clinically detectable laterotrusive IP movement. This finding is in accordance with those of other studies reporting a slight translational movement in alloplastic condyles[32]. It has been reported

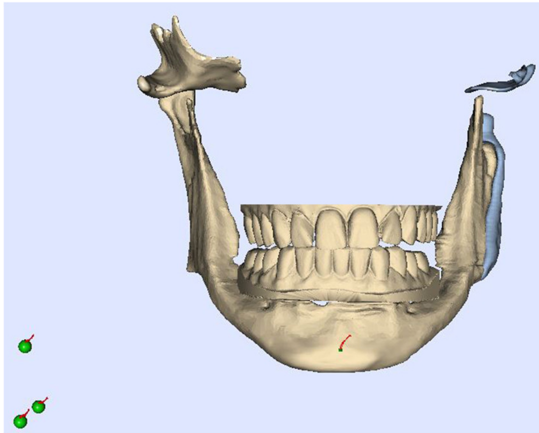

Fig. 6. Trajectory of the mental point during the laterotrusive movement contralateral to the prosthetic joint of patient 4. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories.

that the masseter, medial pterygoid, and posterior temporalis muscles contain fibres capable of generating force vectors with horizontal components[33,34]. Further, suprahyoid muscle activity has been shown by means of surface electromyography during protrusive and laterotrusive movements in healthy subjects[35,36]. It is possible that these muscles could take over the lateral pterygoid function, when this is facilitated by the prosthesis design. This possibility may differ from person to person, as the direction of muscle pull may also be influenced by the height of the mandibular angle: patients with a high mandibular angle will have a greater horizontal force component. In order to strengthen the remaining chewing muscles and inhibit the scar formation of the surrounding tissues, an intensive physiotherapy regime is recommended[32].

The patients presented in this study received prosthetic replacements from the two most frequently applied systems worldwide: TMJ Concepts and Biomet Microfixation. The former is a custom-fitted device and the latter is a stock prosthesis. It has been shown that customized replacements generally achieve better functional results[11]. Furthermore, the two systems differ in their geometry, which most likely influences the kinematic outcomes.

Dynamic stereometry proved to be a highly accurate method of analyzing mandibular kinematics comprehensively. The

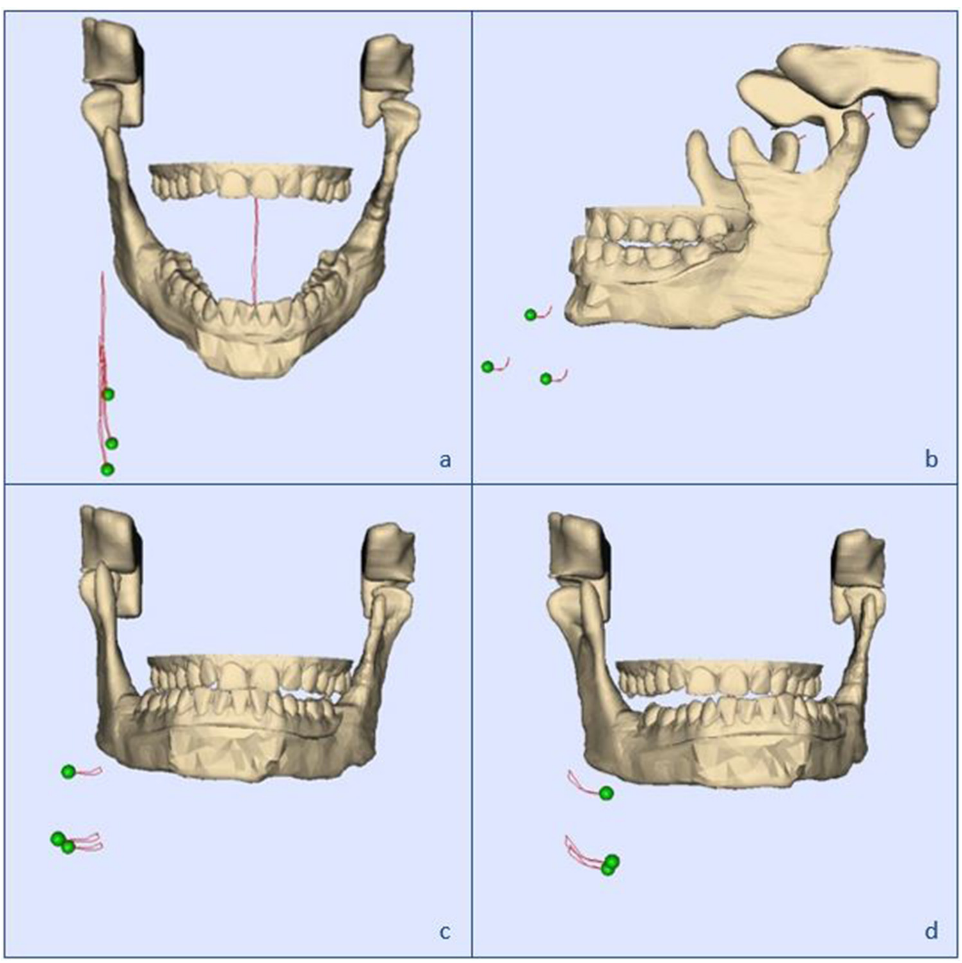

Fig. 7. Trajectories of the inter-incisal point of a healthy control subject. Reference points representing the light-emitting diodes attached to the lower dental arch are shown in green, together with their trajectories. (a) Opening. (b) Protrusion. (c) Laterotrusion to the right. (d) Laterotrusion to the left.

reconstruction error has been estimated at $\leq$1 mm and the greatest geometric distortion measures $<$0.9% in craniocaudal direction[20,37]. With this technique, even minor movements can be visualized and quantified.

The limited sample size did not allow generalized conclusions to be drawn on the various TJR systems and indications. Further studies involving large patient cohorts, segregated by specific system and indication, should be conducted. Moreover, performing electromyographic measurements could possibly increase our understanding of muscular function and compensation after lateral pterygoid resection.

The goal of this study was to demonstrate the considerable variability of clinical outcomes after a TJR surgery. The peculiarity of each case may quickly be forgotten if the data from larger samples are averaged. Therefore, the broad spectrum of TJR indications and the associated variability in pre- and postoperative function and pain level must always be considered. Thus, it is recommended that the individual prognosis should always be discussed with the patient prior to surgery.

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Competing interests. There are no competing interests.

Ethical approval. The Ethics Committee of the State of Zurich approved this study (KEK-ZH-No 2014-0396).

Patient consent. Not required.

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