4 TMJ Dynamics

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Key Points

- The TMJ is a synovial joint. The disc, which lies between fossa and condyle, creates two compartments which may be functionally considered as two different joints.
- Mandibular position continually changes to efficiently perform mastication, swallowing, breathing, and speech; therefore, various spatial relationships between upper and lower dental arches will continuously exist.
- Opening, closing, and lateral movements require finely coordinated mechanisms.
- Rotation and translation, together with protrusion, retraction, and retrusion, are the premise for TMJ and mandibular movement.
- Condylography is a jaw-tracking technique which allows to assess all components of mandibular movement and its spatial coordinates. It is a helpful diagnostic and programming tool, to be used in conjunction with clinical functional analysis and imaging.

The temporomandibular joint (TMJ) is the joint between the mandible and the temporal bone where all movements of the lower jaw are developed. Such movements occur according to specifically required functions and allow the mandible to be positioned appropriately. Mandibular position continually changes to efficiently perform mastication, swallowing, breathing, and speech; therefore, various spatial relationships—between teeth of the upper and lower dental arches—will continuously and necessarily exist.

Mandibular dynamics and precise changes of position are particularly crucial, for example, during chewing, which is a highly differentiated and specialized task. Depending on the appropriate function being performed (cutting, tearing, squashing, or fragmentation), the relationship between jaws and teeth must adapt. This is possible, thanks to both the morphological differentiation of dental elements and to mandibular movement itself.

Adequate TMJ function assists postural stabilization mechanisms of the whole body and, in addition to this, the role of the stomatognathic system in stress-management is more and more discussed and recognized (Ahlberg et al. 2013; Lobbezoo et al. 2018). An orthopedically stable system is needed in order to clench and brux with limited damage to the participating structures. If such parafunctions occur in functionally and

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structurally unstable situations, and for prolonged periods, significant damage to joints, muscles, and teeth-periodontium may be triggered.

One of the unique traits of the TMJ—which makes it different from any other joint—is that there is a single bone (the mandible) articulating with the cranium via two symmetrical joints. The two TMJs can move with a certain degree of freedom; however, they will always influence one another. Movements will therefore depend on the mobility of both joints, and knowledge of their dynamics is fundamental to understand physiology, pathology, and to perform diagnostics.

When considering mandibular movements, one should also bear in mind the difference between *border movements* and *functional movements*. Any mandibular movement is naturally limited by articular surfaces, ligaments, and teeth (both in terms of dental anatomy and dental position/alignment). Border movements are those which can be performed up to the maximum range of motion and that are also more reproducible. Functional movements are those freely performed during function. They are highly variable, for example, chewing on different food textures will imply a different width of movement and differently orientated chewing strokes, and they occur within the envelope of border movements. This means that the opening movement can occur either at its maximum possible extension (maximum opening-border movement) or up to a certain extent (during chewing or speech). Understanding the different possible extent of motion is also important when performing MRI assessment for disc disorders.

Neurological, muscular, and occlusal features related to chewing and to the other functions are fascinating, complex, and finely coordinated, but it is not within the aim of this handbook to describe them. In this chapter, TMJ dynamics will therefore be discussed.

4.1 TMJ and Mandibular Dynamics

4.1.1 Rotation and Translation

The TMJ, the only movable joint of the skull, is a synovial joint. The disc, which lies between fossa and condyle, creates two compartments which may be anatomically and functionally considered as two different joints. The disco-temporal joint represents the upper (cranial) compartment, while the disco-condylar joint constitutes the lower (caudal) compartment. The disc may erroneously be referred to as a *meniscus*, a terminology which is out-of-date and apparently difficult to eradicate. A meniscus is a functionally passive, semi-solid, and wedge/crescent-shaped cartilage structure, which has ligamentous attachments but does not bear two distinct compartments since it does not divide the joint space. The disc instead separates the articular space into two systems (upper and lower compartments), thus preventing communication between the different joint heads. Structural union between the articular surfaces is therefore lacking; however, functional contact is needed to ensure joint stability. This is why a balanced activity of muscles (muscle tone) is also essential (Okeson 2014).

Two types of movement can take place in the temporomandibular joint: *rotation* and *translation*. Hence why the TMJ can be defined as a ginglymoarthrodial joint (it is both hinged and sliding) (Meyer 1990).

Rotation The condyle–disc joint (lower compartment) is where *rotation* occurs. The medial and lateral collateral ligaments connect the disc to the condyle and rotation of the condyle onto the disc is the only possible movement of the lower compartment in physiological conditions. If one thinks of all movements happening at a condylar level, then they can be visualized as taking place along three planes: horizontal (transverse), frontal (coronal), and sagittal plane, as well as around a rotational axis (Fig. 4.1a–c).

- *Transverse (horizontal) rotation axis*: this axis passes through the two condyles. When the condyles rotate around such axis, opening and closing movements are performed. This is a functional axis and not an anatomical one. It is commonly referred to as *intercondylar axis* and, in gnathological terminology, it is the so-called *hinge axis*. The assumption behind hinge axis location is that it is where a “pure rotation” takes place, with no combined translation. When the hinge axis rotation occurs in

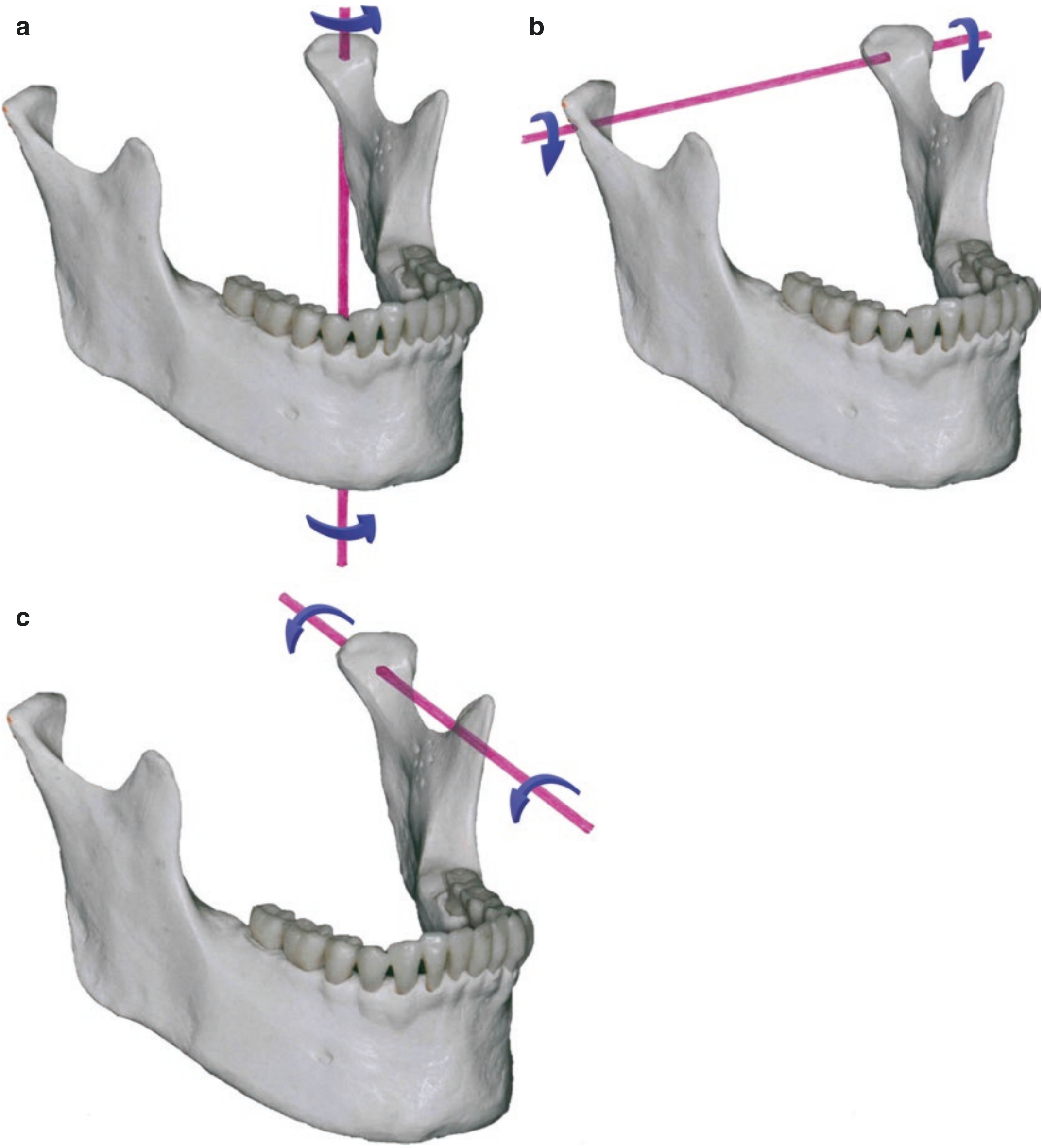

Fig. 4.1 Transverse (**a**), vertical (**b**), and sagittal (**c**) rotation axes of the condyle

centric relation (condyle and disc are centered onto one another and are found in the uppermost part of the glenoid fossa), the result is a *terminal hinge axis*. According to Dawson:

> the axis of rotation passing through the medial poles of both joints causes the possibility of a pure rotation for the first 20 mm of interincisal opening,

- which is then stopped by the temporomandibular ligament (Fig. 4.2a, b) (Posselt 1956; Dawson 2000, 2006). A pure rotation can be demonstrated and recorded, but it rarely takes place as such during function (Okeson 2014);
- *Vertical (frontal/coronal) rotation axis*: this axis passes through the condyle from its superior to its inferior aspect. The condyle rotates around this axis during ipsilateral lateral movements (i.e., when the mandible moves toward the right side, the right condyle will rotate along its vertical axis);

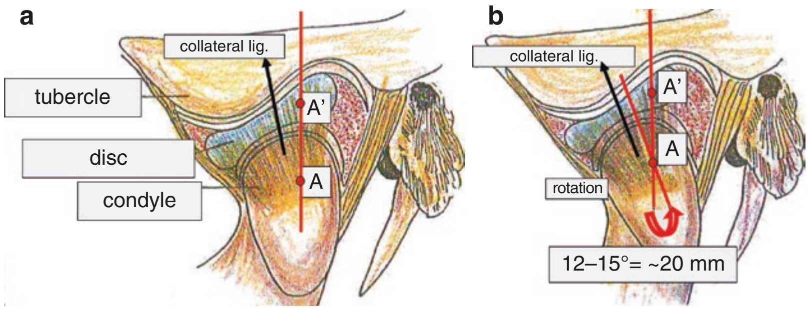

Fig. 4.2 Closed mouth position and relationship between condyle, disc, and fossa (**a**). The disc does not change its position along the eminence during pure rotation of the condyle (**b**)

- *Sagittal rotation axis*: this axis crosses the condyle with a postero-anterior direction. The condyle rotates around such axis when the condyle and mandible on the opposite side lower down (for example, when food is placed between dental arches on one side only).

The above-described movements have been outlined in a very simplified manner for better understanding but in actual facts, they seldom take place separately.

Translation The upper compartment (also known as disco-temporal joint) is where *translation* occurs. This movement takes place between the superior aspect of the disc and the inferior aspect of the glenoid fossa, and results in the condyle shifting along the articular eminence.

For full range of movements to occur, a simultaneous combination of motion in both compartments is needed (Lindauer et al. 1995). Again, partial opening of the mouth may be achieved by rotation alone, but maximum opening can only be obtained if translation in the upper compartment takes place too (Fig. 4.3a, b) (Dawson 2006).

Mandibular activity therefore takes place predominantly in one of the compartments or both, according to the function which has to be performed. In addition to this, when eccentric movements are considered, both condyles move asymmetrically and asynchronously, and one compartment may be mostly engaged in one joint, whereas the other compartment may be more active in the contralateral.

4.1.2 Opening–Closing

On a theoretical level and up to a certain extent, the opening movement may involve the lower compartment alone (rotation). Such opening would only allow a limited separation between lower and upper incisors of approximately 20 mm (Posselt 1956). In the presence of such a small movement, the disc sits and rests in its original, almost unchanged position, and only its ligaments will have some variation of tension. Needless to say, this amount of mouth opening is not sufficient in order to bite and to take food into the oral cavity. An optimal opening can only be achieved when the upper compartment comes into play, thus adding translational motion to rotation. The disc–condyle complex can then slide onto and against the articular eminence (Fig. 4.4a, b). The latter has a downward and forward inclination, which will cause the disc–condyle complex to move along a downward and forward vector, thus originating a wider opening and an interincisal separation which can reach 45–50 mm (even more in some cases). Rotation between condyle and disc can occur anywhere during the forward condylar movement. Closing takes place with the involvement of both compartments and a direction which is opposite to that of opening.

Under a functional perspective, muscles which are engaged during opening are the so-called depressors (suprahyoids and lateral pterygoid muscles), while during closing the elevators are involved (temporalis, masseter, and medial pterygoid muscles). Muscle vectors' action on the condyle is relatively straightforward. The disc, under physiological conditions, maintains its

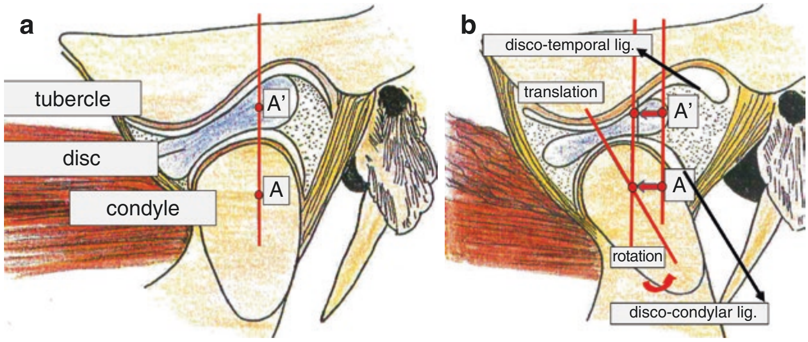

Fig. 4.3 Closed mouth position and relationship between condyle, disc, and fossa (**a**). The disc moves along the eminence and the condyle rotates during opening (**b**)

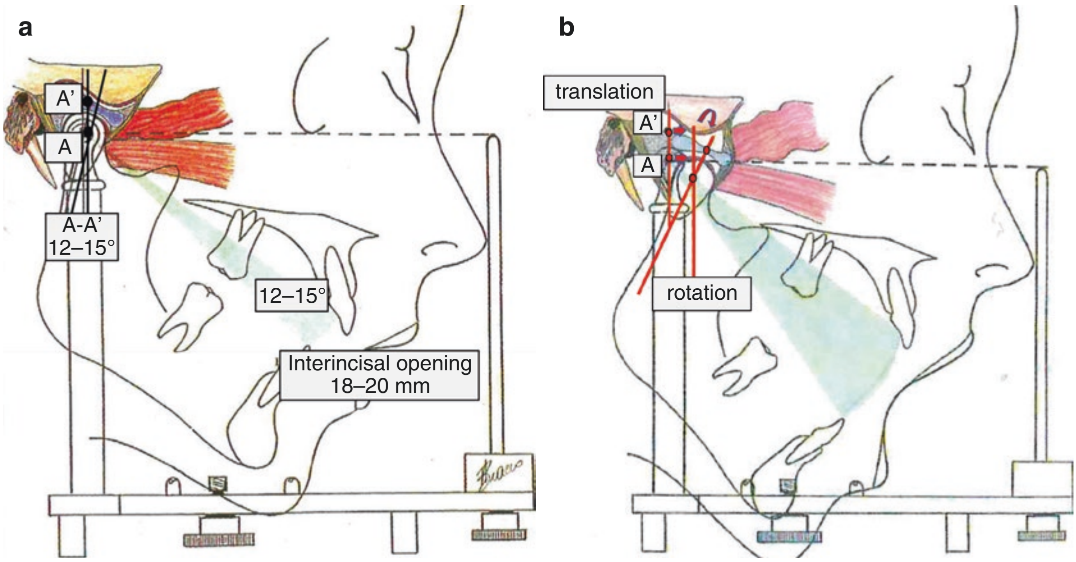

Fig. 4.4 Pure rotation only allows for a small mouth opening (**a**). Translation and rotation together are responsible for maximum opening (**b**). Courtesy of Dr. A. Bracco

position, thanks to the effect of ligaments and muscles (upper head of the lateral pterygoid, see below and Chap. 3) which prevent displacements. The translational component requires a much more sophisticated coordination between muscles and ligaments (Fig. 4.5a–h).

4.1.3 Protrusion, Retraction, and Retrusion

Protrusion This is a forward-directed movement, away from the central position of the joint (where the condyles are in their physiological position in the articular fossa). It is described as the anterior movement capacity in the sagittal plane (Fig. 4.6).

Retrusion This movement is defined in two different ways:

- Retrusion from maximum protrusion (*retraction*) is a movement away from the maximum protruded position, defined as the position where the condyles are in an eccentric position along the articular eminence, and where the relationship between condyle and disc is still maintained under physiological conditions. It is therefore the inversion of protrusion.
- Retrusion from a joint-central position (*retrusion*) is a movement further backward from the point where the condyles are in their physiological position in the glenoid fossa. It is described as the posterior movement capacity

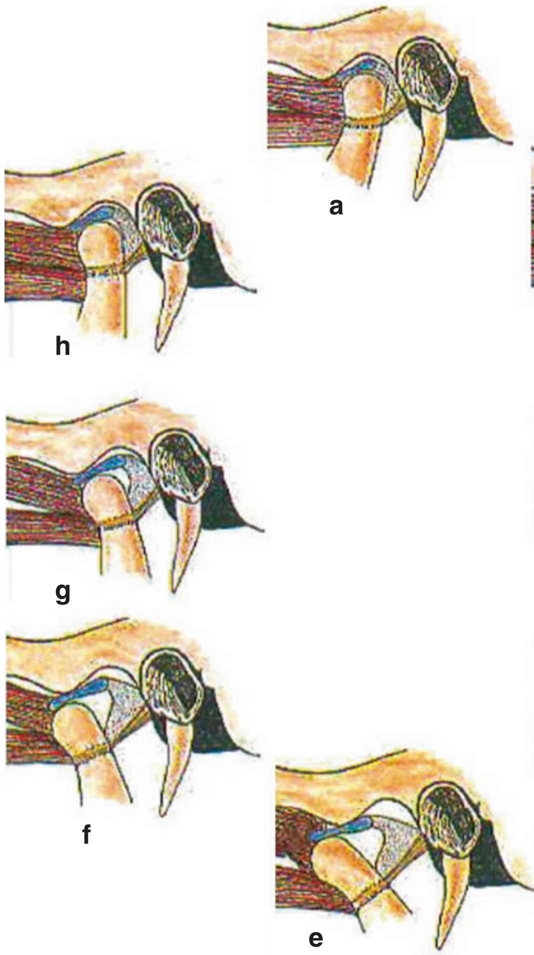

Fig. 4.5 Opening (**a**–**e**) and closing movement (**e**–**h**)—rotation and translation can be seen as well as the upper head of the lateral pterygoid muscle which is at rest during opening and becomes active during closing, thus stabilizing the disc and the joint

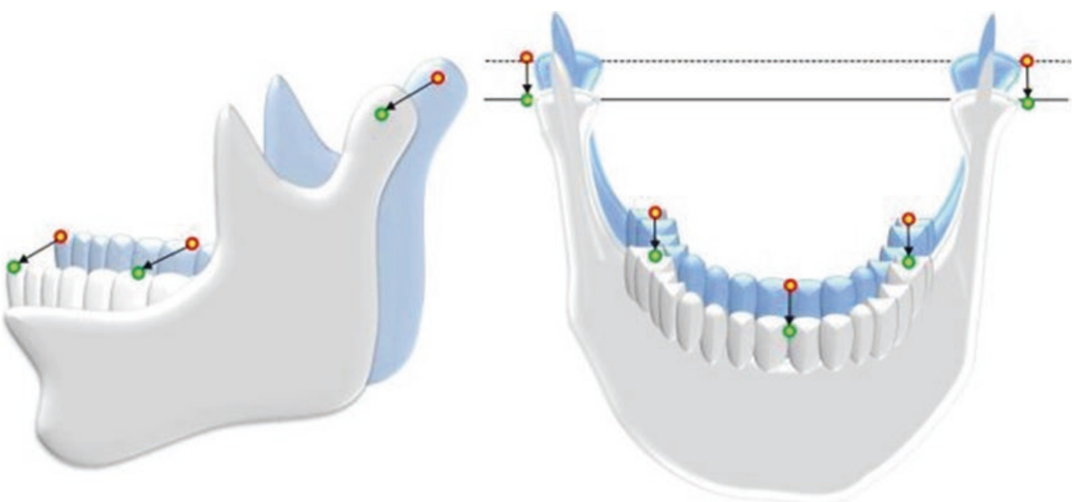

Fig. 4.6 Protrusion—condyle and dental points move forward

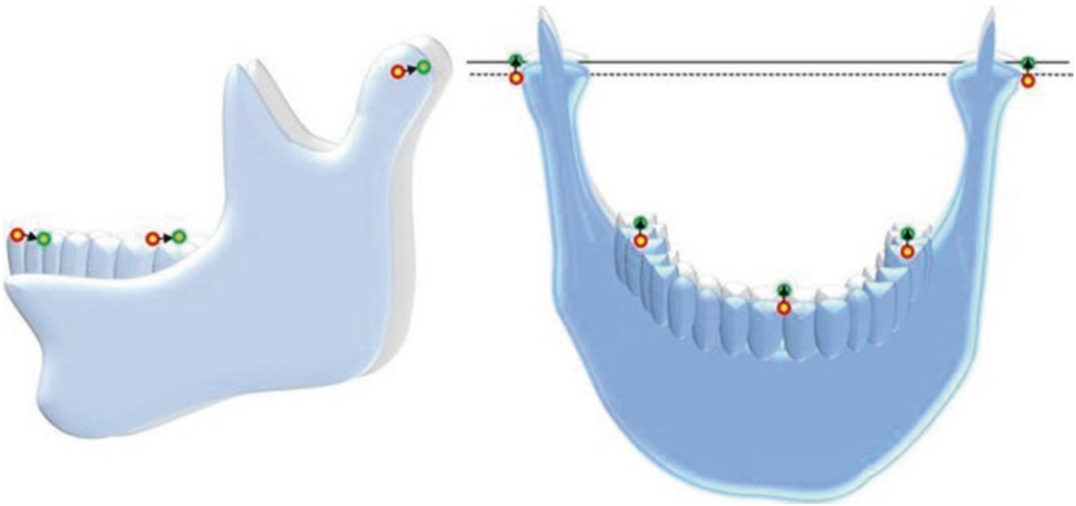

Fig. 4.7 Retrusion—the condyle moves further backward

of the mandible in the sagittal plane, still in close relation to and along the articular eminence (Fig. 4.7).

Protrusion and retraction cannot be considered *primary movements*. In fact, the protrusive and retrusive components are actually intrinsic within the opening–closing movement, as there can be no maximum opening without a certain amount of mandibular protrusion. Similarly, the mandible cannot move back to its starting point if the condyles are not retracted. Protrusion is performed, for example, when whistling, when pronouncing dental consonants, or when divers bite onto their mouthpiece. The muscles which are mainly responsible for mandibular protrusion (translation) are the medial pterygoid muscle and the lower head of the lateral pterygoid, whereas retraction takes place under the combined action of the posterior part of the temporalis and the digastric muscle. Protrusion and retraction are, by definition and under physiological circumstances, symmetrical movements. If, for instance, protrusion takes place on one side only, the result will be an overall lateral movement.

The upper head of the lateral pterygoid has a stabilizing effect onto the disc–condyle complex and plays a major role during retraction. At rest, the tone of the upper head prevails over the retrusive pull exerted by the disco-condylar ligament. When protrusion begins, the disc–condyle complex starts to slide against and along the eminence. At this point, the upper head can be considered inactive. It is, in fact, the lower head to be actively engaged and to be responsible for the movement itself. The collateral ligaments are placed under tension accordingly to the rotation of the condylar head and, at the same time, maintain the disc–condyle complex stable. At maximum protrusion the following will occur:

- the disco-temporal ligament will be tense to its maximum and the disco-condylar ligament will be relaxed,
- the lower head of the lateral pterygoid will show maximum activity and the upper head will be inactive,
- the bilaminar zone, found between the disco-temporal and disco-condylar laminae, will be stretched out and replenished (hydraulic cushion effect) (Fig. 4.8).

Retrusion can be observed during physiological activities such as swallowing. It can be voluntary (by asking the patient to slide further back from maximum intercuspation), or it can take place during parafunctions or because of malocclusions (teeth surfaces sliding against

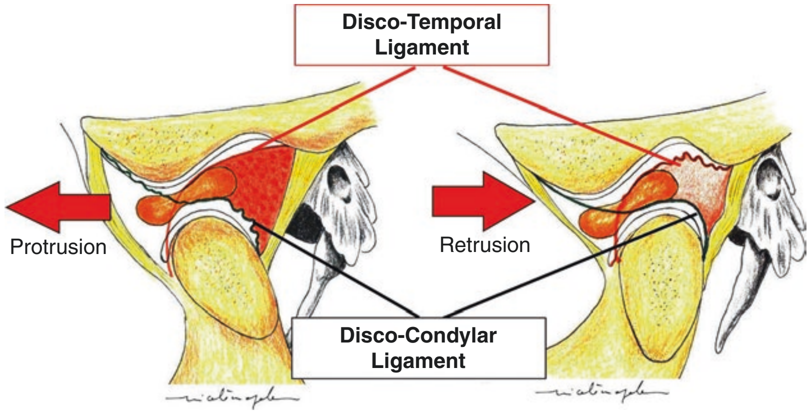

Fig. 4.8 Bilaminar zone and its laminae—changes in protrusion and retrusion

one another and forcing the subject to further retrude so as to reach a proper maximum intercuspation).

4.1.4 Lateral Movements

Mandibular laterotrusion is an eccentric hemi-mandibular movement. In lateral movements, the mandible moves either to the left or to the right as a unit, but the movements which simultaneously take place in the two temporomandibular joints are different. In order to better explain such movement, the midsagittal plane can be taken as a reference plane and the mandible is virtually divided into a right side and a left side. For instance, a mandibular movement is assumed to occur toward the right side. The right side of the mandible will move away from the median sagittal line, thus carrying out a *laterotrusive* movement. The left mandibular side will simultaneously move toward the midline, thus carrying out a *mediotrusive* movement. Laterotrusion is an outward movement and mediotrusion is an inward movement from the central joint position (Fig. 4.9a, b).

- Bodily mandibular movement to the right = right laterotrusion = left mediotrusion.
- Bodily mandibular movement to the left = left laterotrusion = right mediotrusion.

This necessarily implies that two simultaneous different movements take place in the left and right TMJ.

During lateral movements, different muscles are involved. The one which is the most active and responsible for this is the lower head of the lateral pterygoid on the mediotrusive side (mandibular movement to the right, lower head of the lateral pterygoid on the left is mostly active). The protrusive muscles will be active unilaterally on the mediotrusive side so that the mandible can shift toward the opposite side (mandibular movement to the right, protrusive muscles on the left are active). On the laterotrusive side (in this example the right side), elevators will be active, as they maintain the disc–condyle complex in the fossa.

The condyle on the laterotrusive side (in this example the right side) will mainly perform a rotation close to horizontal, and, because of its ovoid shape, an overall movement directed backward and outward. This condyle is also called the laterotrusive condyle, the rotating or the working condyle, as this is the side where tooth contacts are taking place (or chewing, for instance). The condyle on the mediotrusive side carries out a bodily movement directed downward, forward, and inward, following the direction of the fibers of the lower head of the lateral pterygoid. This condyle is also named non-working or orbiting condyle, as no tooth contacts should be present on this side during mediotrusion. In prosthodontics, this is also referred to as balancing condyle as complete dentures can be balanced on this side.

All of the above show how complex mandibular and condylar movements are, and how finely controlled they must be. Once again, the analysis of occlusion, its functions, and how occlusal

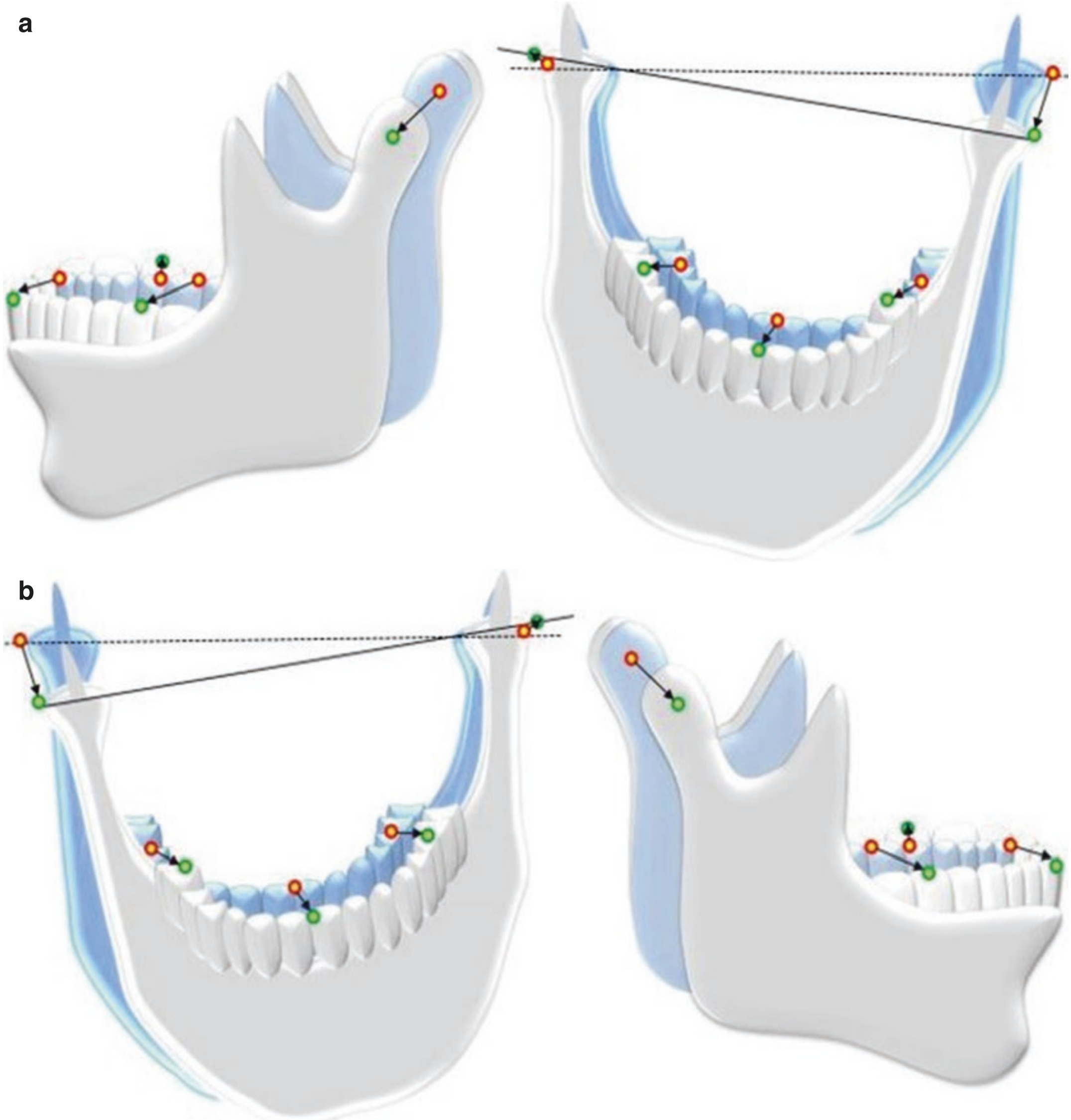

Fig. 4.9 Lateral movement of the mandible. Lateral movement to the right (**a**) can be described as right laterotrusion and left mediotrusion. Lateral movement to the left (**b**) can be described as right mediotrusion and left laterotrusion

architecture is fundamental for a correct distribution of loads is beyond the scope of this handbook. A few considerations must be briefly exposed nonetheless. The thickness of the cartilage differs along the condyle and tubercle. The disc itself shows different thicknesses along its structure. This is because different parts must bear a different load (functional or non-functional) and for a certain period of time. Teeth are also all different in terms of morphology, dimension, and position. During mandibular movements, they must interact correctly to avoid interferences and allow for optimal muscular activity. When the condyle–disc complex slides against the eminence, upper and lower teeth slide against each other too. It is quite easy to understand how the steepness of occluding surfaces must be in harmony with the steepness of the eminence in order to allow for the correct alternation of compression and decompression within

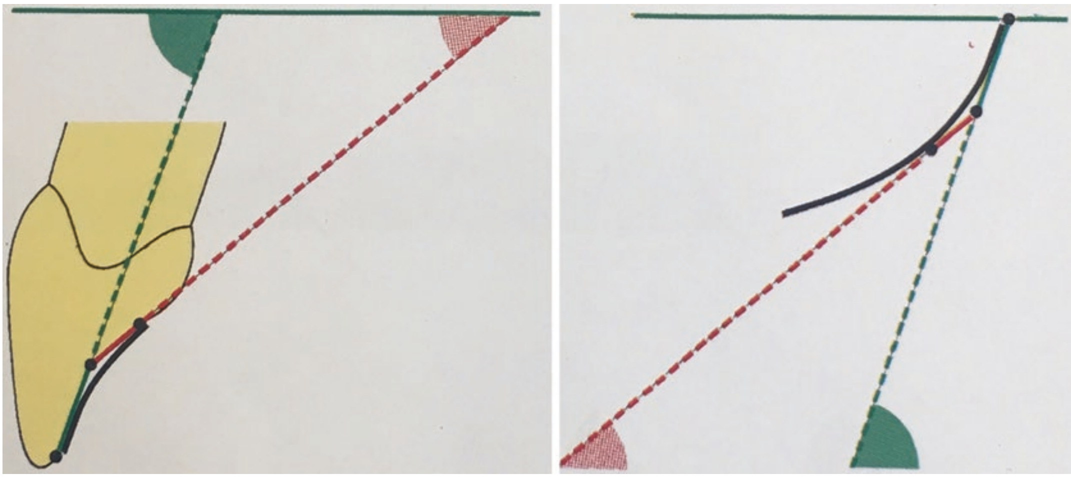

Fig. 4.10 The palatal aspect of the upper incisor (*left*) is the guiding structure of teeth-guided protrusion, and its shape is inversely related to that of the articular eminence (*right*) (from A.I.G. 1994)

the joint. Moreover, an inverse correspondence between the shape of upper front teeth lingual anatomy and the anatomy of the joint surfaces has been studied extensively (Slavicek 1984). During mandibular movements, when structural contact is taking place on a very steep part within the joint, the dental contact is taking place on a flatter one and vice versa (Fig. 4.10).

4.2 Focus on Condylography: Understanding Mandibular Movement

As seen in the previous chapters, the temporomandibular joint is a complex entity, in both structure and function. A profound understanding of its complexity is of central importance during clinical and instrumental examination and will influence treatment planning. This characteristic is clearly highlighted in a quote from Mariano Rocabado:

> In order to understand how a joint that maintains such a close environment can become unstable, lose its normal mechanics, and start functioning against the rules of synovial joints (movable, friction-free, and pain-free joints), we must understand the normal physiology of joints and of periarticular connective tissue, mainly, ligaments and capsules (Rocabado 1983).

Condylography is a tool that can address these demands. It completes and supports the field of clinical functional analysis and, as such, it is attributed to the so-called instrument-assisted clinical functional analysis. It provides the operator with graphical representation of the movements carried out by the joints, and it gives the possibility to take a closer look at the movement pattern of virtually any mandibular structure, as the recording system and the software enclose the subject into precise three-dimensional geometrical coordinates.

In order to do so, a clutch is temporarily secured to mandibular teeth onto their vestibular surface (paraocclusal clutch) or on their occlusal surface (occlusal clutch) (Fig. 4.11). An upper bow bears the digital recording flags, whereas a lower bow is attached to the mandible through the clutch and bears the recording stili on both sides (Fig. 4.12a–d). These are double stili as one is dedicated to the hinge axis and one is for rotational evaluations. The recording apparatus is connected to a transducer and thus to a computer where the software interface allows for visualization of the live recording and for storing it.

It should be emphasized at this point, that using condylography to record joint path movements by no means replaces a thorough clinical functional analysis or manual examination and palpation of the temporomandibular joint. Instead, it should be seen as a necessary complement to these procedures, in terms of providing a

Fig. 4.11 Paraocclusal clutch used for condylographic recording

depth of diagnosis that has the clear potential to detect pathological changes in their early stages. Condylography can enable the well-trained and experienced user to detect signs of disorder before they become clinically apparent and even before the patients themselves become aware of any discomfort. More clearly, this analysis allows to identify findings as belonging to bony structure, disc/ligaments, and muscles. Condylography should not be understood as an alternative to radiological imaging, but as a possibility to come up with a valid confluent diagnosis. Not to mention that it could also be a powerful tool in the perspective of saving useful resources in the hospital setting, or at least use them wisely, so that in selected patients and conditions, they can be employed for other purposes rather than interim and final analysis. Reliability studies still have to validate this instrument, which is traditionally part of gnathology, together with MRI findings, as it gives more refined information than clinical findings alone.

This overview demonstrates where condylography fits into the analytic process that has to be considered in any TMJ patient that is referred to a dentist or maxillofacial surgeon:

- Clinical functional analysis
- Instrument-assisted clinical functional analysis (condylography, cephalometry)
- Instrumental functional analysis (articulator)
- Additional diagnostic methods (MRI, CT scan, X-rays, US)

Condylography aims at detecting early changes in the biodynamics of the temporomandibular joint and its associated structures. Diagnosis is based on the principle of recording the dynamics of the hinge axis. The careful interpretation of the condylographic diagnostic findings can highlight alterations related to the articular disc, the ligaments of the craniomandibular system, the joint capsule, the condyle, the fossa, the neuromuscular system, and occlusion. This section is not aimed at providing the reader with an "atlas" of condylographic interpretation, but rather at walking beginners and advanced users through the biomechanics principles that can be evaluated and understood instrumentally.

4.2.1 Principles of Condylography

Condylography is based on the idea that the entire range of movements of the lower jaw can be repeatedly and reproducibly recorded and presented in graphical form. Condylography as a method for evaluating mandibular movements has its predecessors dating as back as the last decades of the 1800s. The first recordings were reported by Ulrich and Walker, and invaluable contributions to the study of hinge axis, Bennett movement, jaw tracking, articulator programming and for diagnostic purposes have been made by Bennett, Eltner, Gysi, McCollum, Posselt, Messerman, Bewersdorff, Jankelson, Lundeen, Alsawaf, Missert, and Slavicek (Piehslinger et al. 1991). Continuous improvements in the technique have been observed until today, together with technological advances, so that electronic condylography performed nowadays links the geometrical knowledge of traditional condylography together with the possibilities of the so-called *advanced condylography* (insights into translational and rotational movements, quantity of rotation, velocity assessments, graphical representation of the end feel, and so on).

The movements of the mandible are highly diverse, complex, and three-dimensional, limited in range and motion by few structures: teeth,

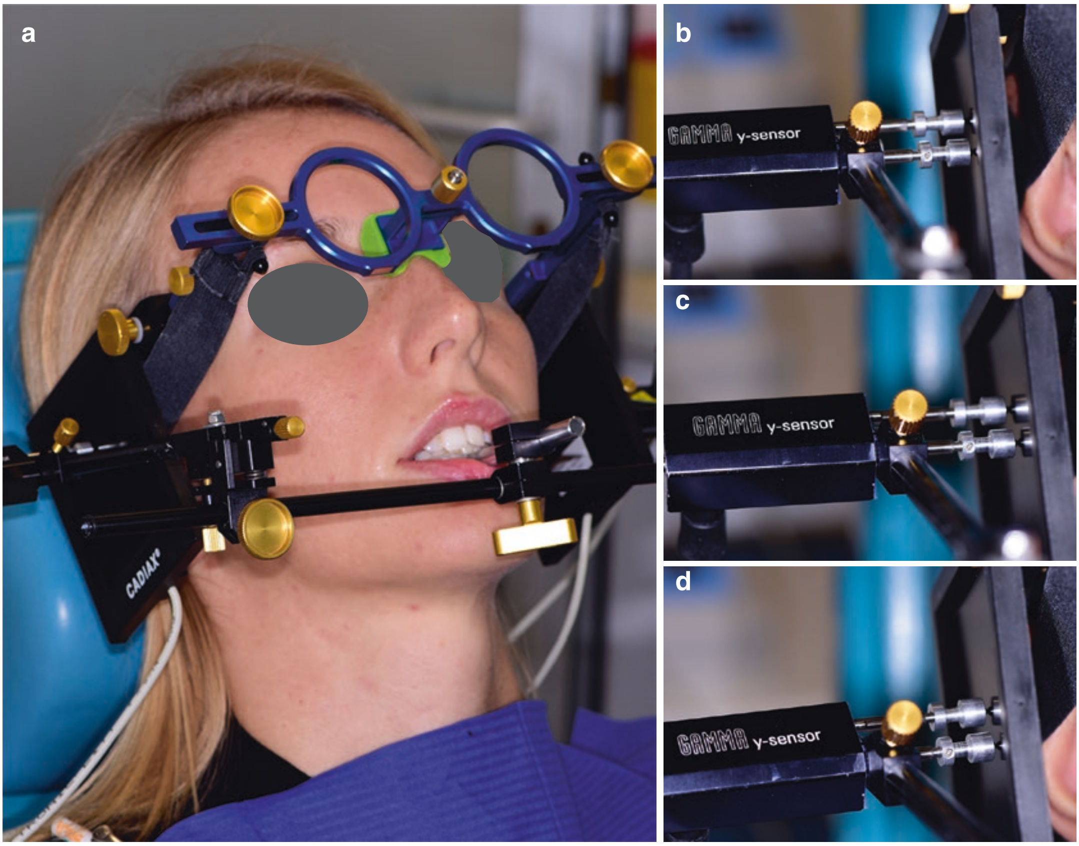

Fig. 4.12 Condylographic hardware—upper bow with digital flags and lower bow with double stili (**a**). The double stili allow for recording of the hinge axis movement and rotational information. Right mediotrusion movement while being performed and recorded (**b**–**d**). The stili can be seen to intrude more and more inside their slot as the movement takes place

ligaments, muscles, and soft tissue (Rocabado 1983; Koolstra and Van Eijden 2007). Teeth represent the vertical limiting structures for the closing movement of the mandible. This is of course also true for dentures or the alveolar ridge in the edentulous mouth. Dental surfaces are modifying determinants of protrusion, laterotrusion, and retrusion. Ligaments limit the range of posterior motion, while muscles and soft tissues limit the opening and sideways movements.

In healthy humans, there are no limitations to lower jaw movements due to bone. The fossa and the articular eminence give the mandible a great deal of freedom. And when considering the dynamics of the temporomandibular joint, it would be wrong to assume that the glenoid fossa of the temporomandibular joint holds a dominant control function in terms of locating and determining mandibular position. On the other hand, the articular eminence controls the forward movement during protrusion, opening, and mediotrusion and allows the condyle–disc complex to slide along it. But it can be clearly seen in joint path recording that this movement usually stays within the tubercle and does not necessarily go over and beyond this bony structure. This can be observed in physiological situations, particularly in the functional movements of the mandible, especially during chewing.

Mandibular movements are often described as *border movements*, based on their spatial complexity. Once again border movements are those that display maximum range in all directions of space, and these cannot be exceeded under physiological conditions. This applies to forward movement, lateral movement, opening and posterior movement. These extreme movements can now be reproduced in two-dimensional representations, i.e., on the sagittal, transverse, and cranial planes (Fig. 4.13), and as points of a mandibular movement pattern (Fig. 4.14a, b) (Posselt 1952, 1962).

At this point one essential factor should be stressed about the description of mandibular

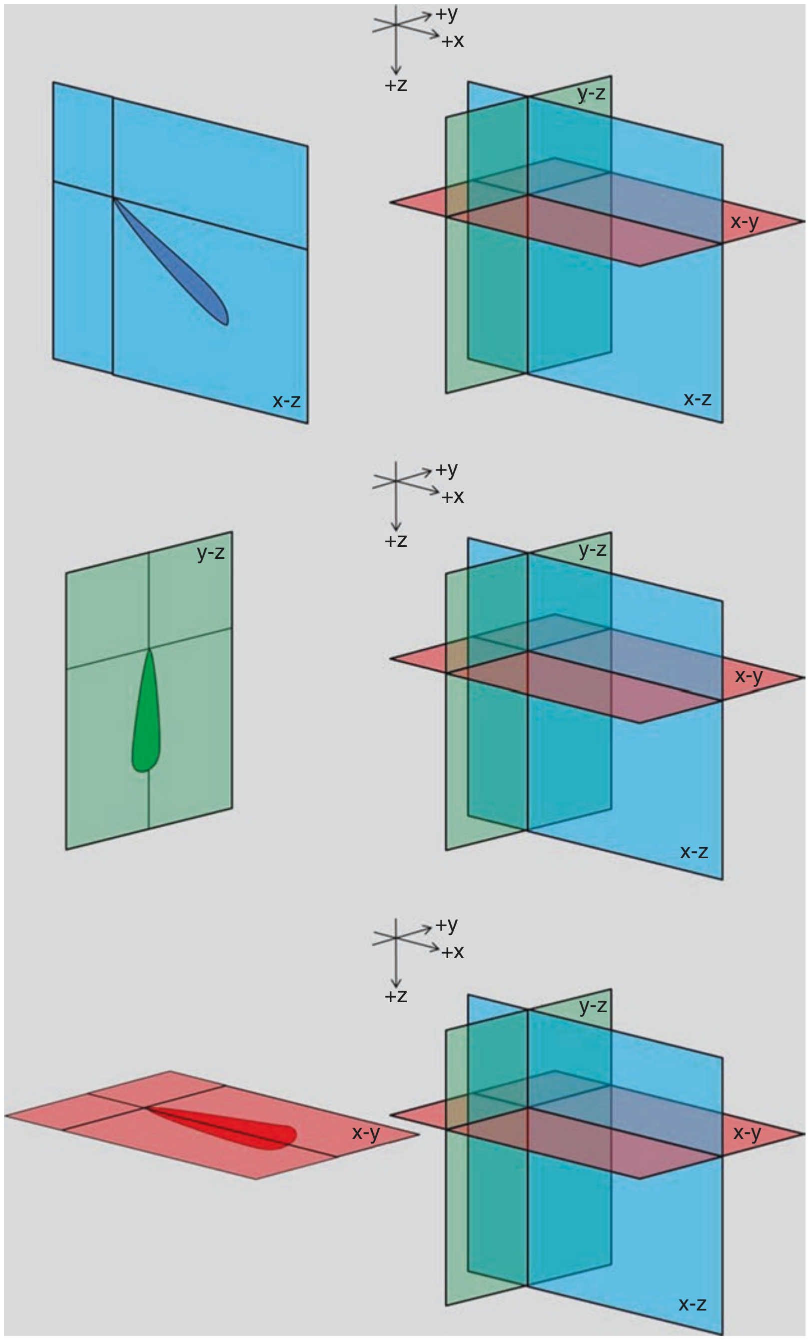

Fig. 4.13 From top to bottom—sagittal (x–z), frontal (y–z), and cranial planes (x–y) on which hinge axis movement can be displayed

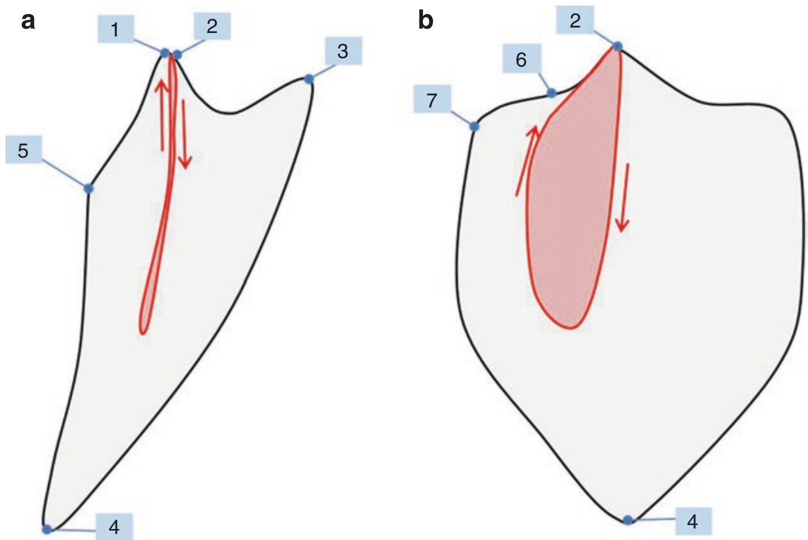

Fig. 4.14 Points of mandibular movement pattern are here displayed in sagittal (**a**) and frontal (**b**) view

movement: it is of major importance to specify the physical (anatomical) point at which the border movements are observed. In fact, one occlusal point will show a very different movement pattern as opposed to another occlusal point and opposed to jaw joints (Koolstra et al. 2001; Tanaka and Van Eijden 2003). The reason for this lies in the fact that during movement, the temporomandibular joint does not stay in one position within the articular fossa. The joint permits rotational movements and, in fact, rather wide translational motions, and the original position in relation to the fossa is abandoned all the time. The result is a compound motion that is a combination of translation and rotation. In addition, the movement of the mandible is determined not just by one but by both temporomandibular joints, moving in either a symmetric (opening and protrusion) or asymmetric (laterotrusion and mediotrusion, respectively) way. Within the range of the above-mentioned border movements, the actual movement sequences now take place with the execution of movements such as the ones for chewing, swallowing, speaking, breathing, pressing, grinding, postural support, and body balance.

Having said this, recording such mandibular movements represents a very complex and demanding task for the recording instruments which are used, whether mechanical or electronic. In the analysis of mandibular movement, it is fundamental to always distinguish between analyzing the movement of the TMJs themselves and the movement of other components expressed as TMJ movement. This should generally be considered in the underlying method and instruments used (i.e., intra- or extra-oral recording) (Lundeen and Wirth 1973; Mauderli and Lundeen 1991; Miller et al. 1995; Currie 2010).

4.2.2 Mandibular Movements

Mandibular movements are versatile and complex. When defining and describing such movements, one necessarily has to specify which part of the recorded system is being displayed: this could be the hinge axis, any point of occlusion, and any mandibular part such as the chin. Typically, mandibular movement is first analyzed through standardized movements (Fig. 4.15a–d):

- Protrusion
- Retraction
- Retrusion
- Laterotrusion
- Lateroretrusion (from maximum laterotrusion back to the central starting position)
- Mediotrusion
- Medioretrusion (from maximum mediotrusion back to the central starting position)
- Opening movement (abduction)
- Closing movement (adduction)

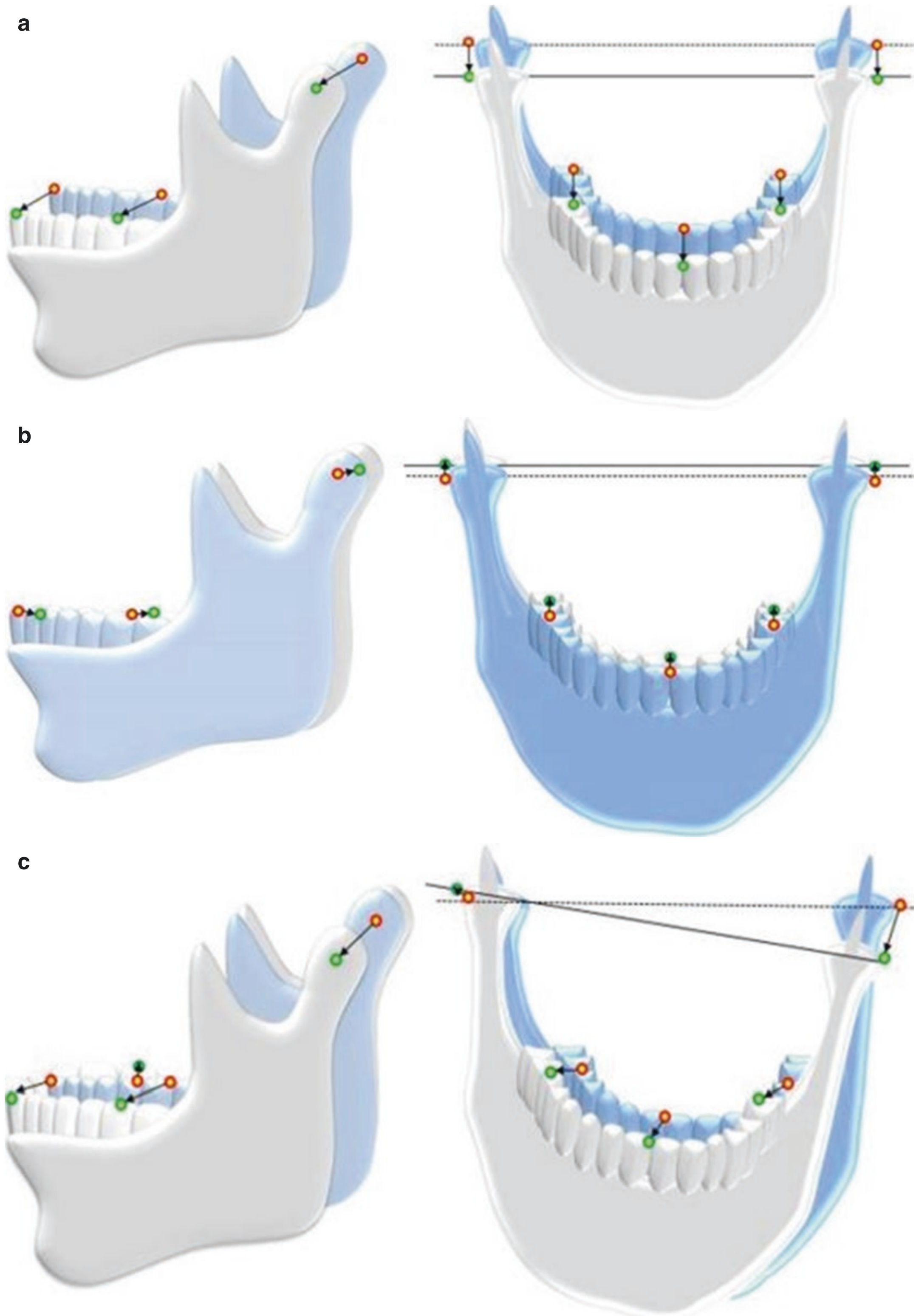

Fig. 4.15 Protrusion (**a**), retrusion (**b**), opening (**c**), and right laterotrusion/left mediotrusion (**d**)

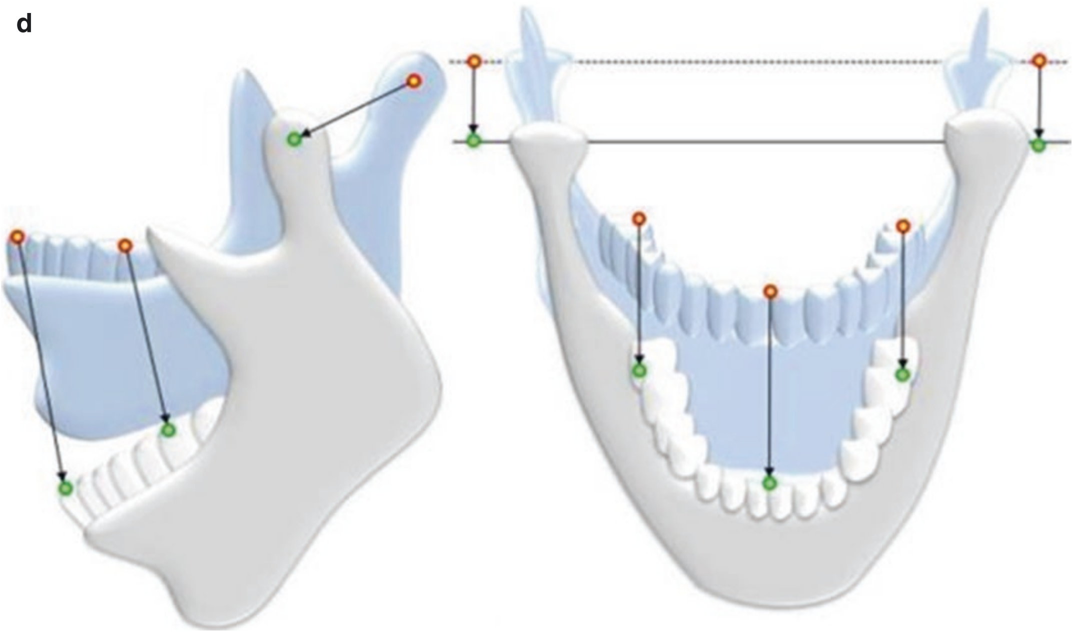

Fig. 4.15 (continued)

All these mandibular movements can now be performed during the study in several ways:

- *Free movement*: the test subject or patient moves spontaneously without any contact of teeth. These are the standard movements that are primarily used for the evaluation. The influence of occlusion on movement patterns and dynamics of the mandible is reduced, but not eliminated completely, as the programming (or memory) of the neuromuscular system will still show its flaws.
- *Guided movement*: the test subject or patient is asked to move the mandible under the guide of tooth contacts. The influence of occlusion on the paths of movement can be seen here. These pathways provide a basis for further analysis of functional movements. Such movements cannot be recorded in case an occlusal clutch is used.
- *Manipulated movement*: the examiner influences the movement through active manipulation of the mandible in one direction. These movements enable the differential diagnosis of various pathologies of the TMJ (such as internal derangement) and the stomatognathic system.
- *Functional movements* (functions): the test subject or patient is asked to perform functions, as standardized as possible. Typically, chewing (with or without swallowing), talking, clenching, and grinding will be recorded.
- *Extra* (specific movements): depending on anamnestic data, clinical functional analysis results, or findings from instrumental analysis, it may be advisable to record specific movement patterns that are to be incorporated into the overall analysis. An example of this is the possibility of showing movement patterns on an occlusal splint to evaluate its therapeutic effects.

Besides movement analysis, other parameters can be recorded and analyzed during condylography. This is the case of *end feel*, for instance. This is adopted from traditional orthopedics where it is defined as the quality of resistance at the end of a movement. An end feel is pathological if it has a different quality than expected, and if it occurs at a point in time other than under physiological conditions. Assessing the end feel involves a passive movement test (Freesmeyer 2011). Four typical physiological end feels are found in the assessment of joints:

- soft-elastic: caused by interposition or stretching of muscles.
- firm-elastic: caused by the limiting effect of the capsular ligaments.
- hard-elastic: caused by the physiological function of the cartilage.
- hard-inelastic: limitation of movement by bony structures.

The TMJ is usually soft-elastic (in protrusion, laterotrusion, and opening) and firm-elastic (in retrusion and in caudal and cranial manipulation).

4.2.3 Forward Movement (Protrusion)

During protrusion, the lower jaw moves forward, out of a position where both condyles are in the fossa. The movement path is largely determined by the articular eminence and dental structures. Rotation only occurs to a limited extent and this depends on the dynamic connection between the lingual morphology of the front teeth and the morphology of the fossa and eminence (Slavicek and Lugner 1976; Slavicek 1984; Slavicek 2011). Forward movement is limited due to increased tension in the muscles and soft tissues, giving a soft end feel. A hard end feel does not occur with this motion under physiological conditions.

The determinants of protrusion are:

- Articular eminence (on both sides)
- Condyle–disc complex
- Lingual morphology of the upper front teeth

The modulators (major influential factors) of protrusion are:

- Occlusion in the posterior region
- Skeletal and/or dental asymmetry
- Shape and orientation of the condyles
- Skeletal class
- Neuromuscular system

The Posselt diagram shows a characteristic image of movements of mandibular dental structures—for example, the lower incisor (Posselt 1952, 1962). This can be represented as a three-dimensional envelope curve. Viewed from the side, the movement of the jaw is seen to be very simple in principle, due primarily to the defined trajectory of the articular eminence. Viewed from the cranial direction, and equally from the front, the physiological protrusive movement path is seen to be straight with no deviation to the side. This is a symmetric movement of the mandible (Figs. 4.15a and 4.16).

In the forward movement of the lower jaw, the temporomandibular joints move along a trajectory, which is largely determined by the curvature and slope of the articular eminence under physiological conditions. For the lower front teeth, under physiological conditions, protrusion is dominated by the upper front teeth and can be represented by the characteristic movement seen in the Posselt diagram (Fig. 4.17a, b).

4.2.4 Backward Movement (Retraction)

In terms of the TMJ, the backward movement from maximum protrusion should be, under physiological conditions, identical to that of protrusion. Again, the path of the front teeth may be traced over the previous; however, this does not normally happen, instead the movement is performed either with the same or with a greater opening rotation than in protrusion, without anterior control, and the movement ends with a closing rotation. There are no bony or dental structures that limit the backward movement of the mandible from the maximum excursion. Ligaments do play a certain role, but the action of centering the mandible that concludes the backward movement is essentially controlled by the muscles of the craniomandibular system.

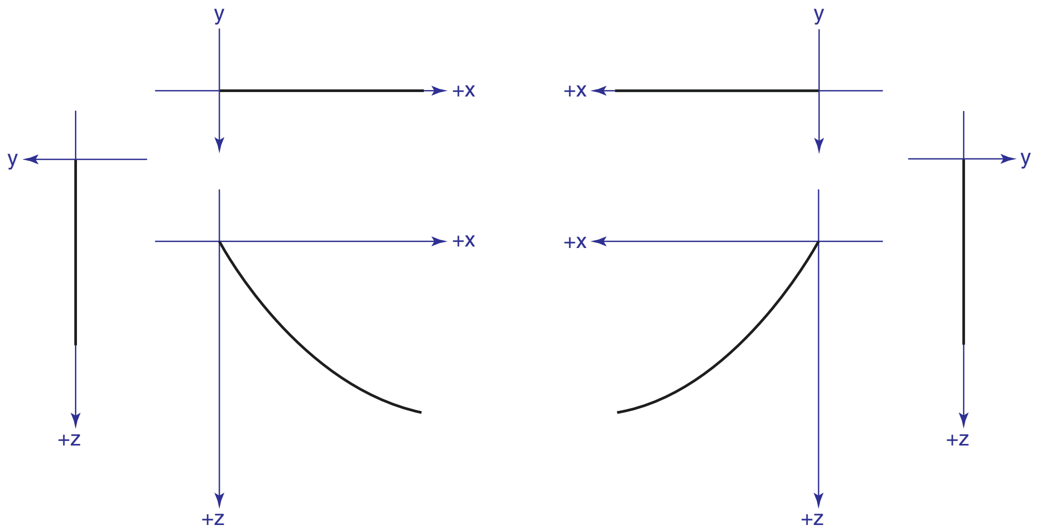

Fig. 4.16 Protrusion tracing for the right and left joint. Each side has its movement displayed on all three planes. Protrusion is symmetrical and no lateral displacement should be seen on the frontal and cranial plane (where a straight line is observed). Sagittal view shows a physiological concave characteristic of the curve

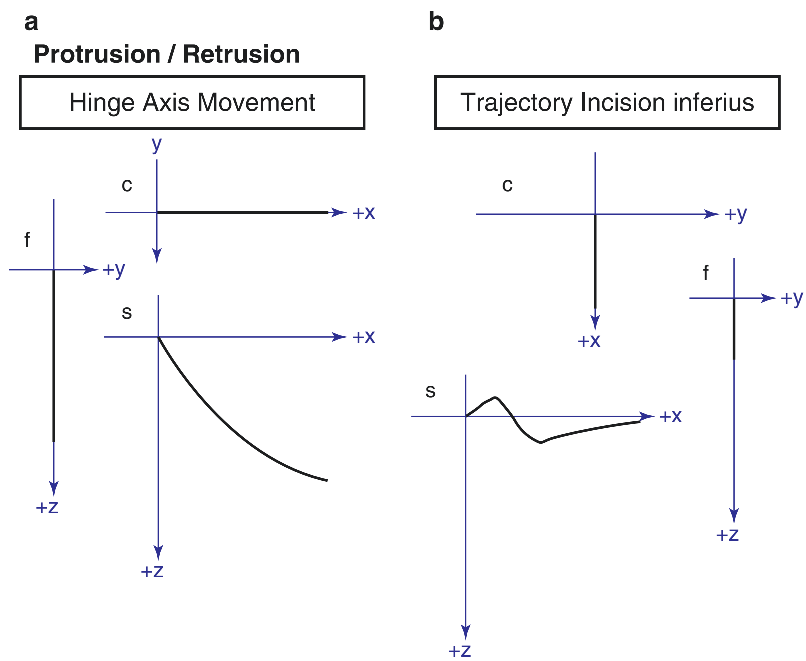

Fig. 4.17 Condylographic aspect of protrusion on the frontal (*f*), coronal (*c*) and sagittal (*s*) planes (**a**). Lower incisor movement (**b**) can be studied in advanced condylography. This movement depends on the upper teeth morphology and its tracing corresponds to the upper part of the envelope of border movements (Posselt scheme)

As the mandible moves backward from the maximum protrusive position, the temporomandibular joints perform a movement that, under physiological conditions, is largely determined by the curvature and slope of the articular eminence. Here, it is possible to see influence of the articular disc and position of the ligaments and to note that they come into play earlier than in protrusion. The reason for this lies in the direction of muscle vectors that are active in protrusion and retraction/retrusion, respectively (Fig. 4.18a, b). The front teeth are said to have an indirect influence on this movement, in the sense of avoiding contact, so that the upper front teeth have no contact in retraction

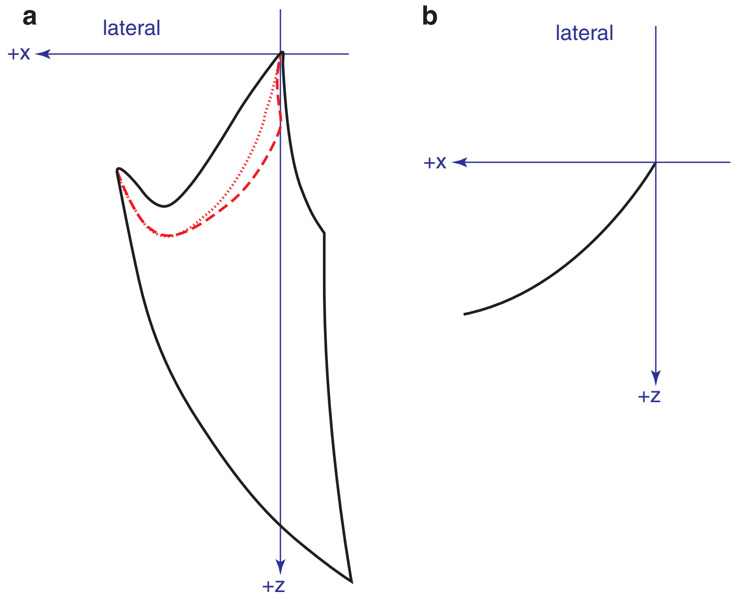

Fig. 4.18 (**a**) Lower incisor movement in retraction (*red*) shows that upper teeth are avoided. At a joint level (**b**), the condylographic aspect of retraction is a concave curve

and are bypassed. The retraction and protrusion paths of the lower front teeth will differ according to physiological conditions and will be characterized by a larger opening rotation of the mandible in moving backward, and a late-occurring closing rotation on occlusal contact. To put it another way, while protrusion is executed as a border movement, this is not expected to be the case for retraction. In retraction, the movement paths of the teeth in the posterior regions differ from both the TMJ motion path and that of the front teeth of the mandible. However, it should be noted—again assuming physiological conditions—that the left and right sides of the occlusion move almost identically. At the end, when the condyles reach their position in the joint fossa, the movement is controlled and regulated by muscles. As there are no bony structures to protect the back of the temporomandibular joint in humans, the end feel is elastic. A hard end feel at the end of this movement is not present under physiological conditions and, if present, it would indicate pathology.

4.2.5 Backward Motion (Retrusion)

The mandible moves backward from the position where both condyles are positioned in the fossa (Fig. 4.15b). The movement pattern is fundamentally determined not only by the articular fossa and the articular disc, but also by dental structures. Rotation only occurs to a limited extent and this depends on the dynamic connection between the steepness and position of tooth contacts during this movement. The front teeth are usually not involved, except in the event of an anterior crossbite. Contact in the molar region, in the areas behind the transverse crest (crista transversa) of the first upper molar, is particularly critical to these movements. Backward movement is limited due to increased tension in the ligaments (in this case primarily the temporomandibular ligament). In humans, there is no bony restriction to such movements, due to the absence of a distinct post-glenoidal process and the orientation of the articular fossa and the TMJ (Fig. 4.19a, b). In any case, a hard end feel is not observed with this movement, although, with well-aligned ligaments, the difference in the end feel between active movement (engaged by the patient) and passive movement (manipulated by the practitioner) is negligible.

The determinants of this movement are:

- Articular fossa (on both sides)
- Condyle–disc complex
- Active retrusive occlusal contact (ideally in the upper premolar area)

The modulators (major influential factors) of this movement are:

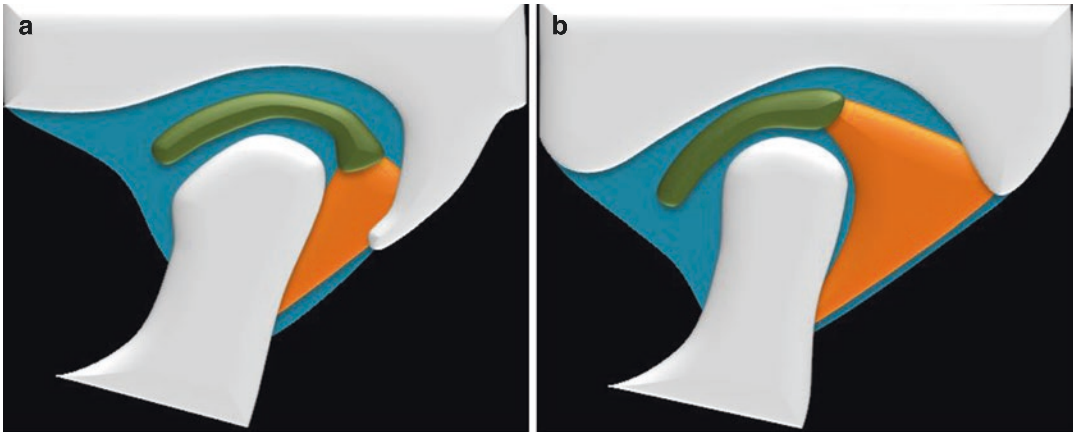

Fig. 4.19 (**a**) Post-glenoid process limits posterior movement of the condyle; however, this structure is different in the human TMJ (**b**), where there are no bone limitations to movement other than the fossa

- Individual articular position
- Occlusion in the posterior region (often one-sided)
- Skeletal and/or dental asymmetries
- Shape and orientation of the condyles
- Skeletal class
- Neuromuscular system

4.2.6 Lateral Movements (Laterotrusion, Mediotrusion)

In lateral movements, the mandible moves from the position at which both condyles are in the glenoid fossa, toward one side, left or right (Fig. 4.9a, b). For the most part, the movement pattern is determined by the articular eminence and the articular fossa on the mediotrusive side, the shape and position (in terms of orientation) of the condyles on both the medio- and laterotrusive sides, and the dental structures on the laterotrusive side. Rotation only occurs to a limited extent, depending on the dynamic connection between the lingual morphology of the canines and the morphology of both the eminence and the fossa on the left and right sides (Slavicek and Lugner 1976, 1979; Fialka et al. 1990; Slavicek et al. 1990). Sideways movement is limited with increased tension of the muscles and soft tissue, giving a soft end feel. A hard end feel does not occur with this motion under physiological conditions.

The determinants of this movement are:

- Articular eminence (especially on the mediotrusive side)
- Condyle–disc complex (on both sides)
- Lingual morphology of the canines and upper lateral incisors
- Any guiding (controlling) premolar or first maxillary molar structures on the laterotrusive side
- Articular fossa (on the laterotrusive side)

The modulators (major influential factors) of this movement are:

- Occlusion in the posterior region
- Skeletal class
- Individual articular position of the condyle in the articular fossa (habitual position)
- Skeletal and/or dental asymmetries
- Shape and orientation of the condyles
- Neuromuscular system

In lateral movement, the teeth of the mandible on the mediotrusive side move with a forward, inward, and downward motion. In the same movement, the laterotrusive side of the occlusion moves with a sideways, downward, and outward motion. Due to the geometry of the mandible, the paths of movement at various points of the mandible are significantly different. Albeit a simplification, this can be illustrated in the form of a triangle with two points at the left and right temporomandibular joints and a third at the lower anterior point.

In a lateral mandibular movement, the non-working condyle makes a wide and sweeping motion, forward, downward, and inward. In the same movement, the range of motion of the working side is, by contrast, small and often only perceived in the sense of rotation. Depending on the geometrical position of the rotation axis and on the shape of the condylar head itself, some part of the condyle may undergo a backward rotation or a forward rotation. A pure rotation may also be the case. Anyway, the scope of condylar movement is comparatively very different on the latero- and mediotrusive sides. The lower incisal edge moves forward (due to the extensive movement of the non-working condyle), toward the laterotrusive side (again, due to the wide motion of the non-working condyle), and downward (because of the connection between the non-working and working condyles). For simplicity, it is assumed here that the incision inferior is positioned in the medial sagittal plane and that the path of movement is not influenced by the upper front teeth. The downward component of the movement is influenced by the action of the working condyle: a more extensive backward and upward movement of the working condyle flattens the trajectory of the lower incisor, while an excessive backward and downward movement of the working condyle gives a significantly steeper trajectory of the lower incisor (Fig. 4.20).

Occlusal structures of the mandible, such as the cusps of canines, premolars, and molars, move differently: the laterotrusive side moves noticeably out and down, while the mediotrusive side moves forward, inward, and downward. The influence of the working condyle should be noted on the laterotrusive side. The movement paths of the cusps on the laterotrusive side can then vary in direction and achieve a forward or backward movement component. In the Posselt diagram, this movement can be seen when viewed from the front or from a cranial view (Posselt 1952, 1962).

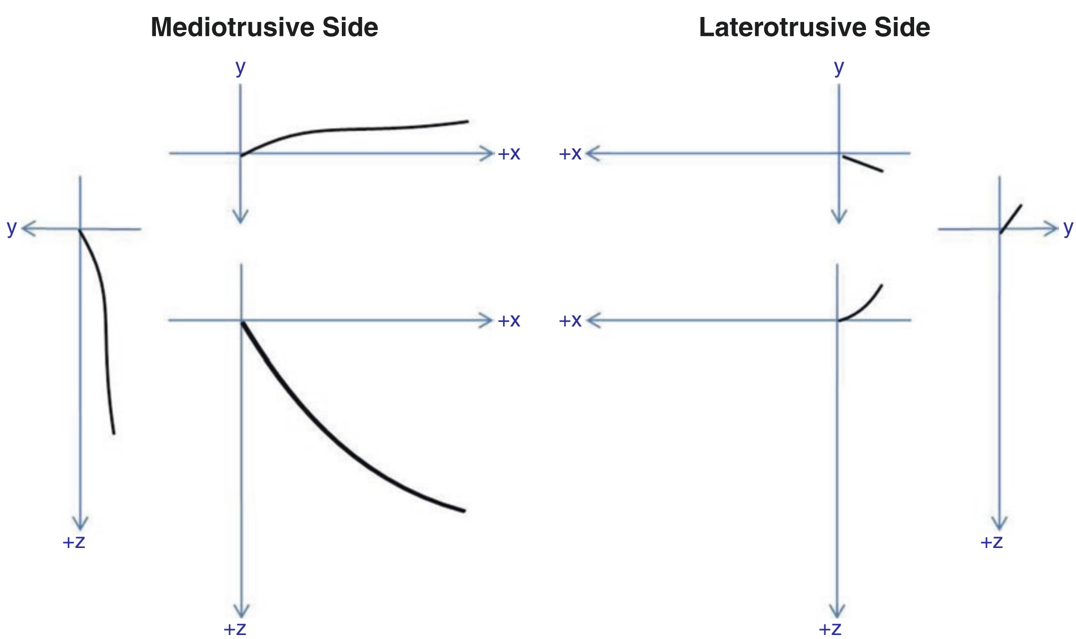

Fig. 4.20 Mediotrusion of the right joint and laterotrusion of the left joint. This compound movement corresponds to mandibular lateral movement to the left. The mediotrusive side moves inward, downward, and forward and the graphical representation of the laterotrusive side results in an upward, outward, and backward movement

Observing the Working Condyle (Laterotrusive Condyle) The working condyle is the one situated on the side toward which the mandible moves. In this sideways movement, the working condyle only has a limited range of motion that is often described as rotational. In gnathology, and particularly in condylography, the direction of movement of this side is specified with the terms pro-, sur-, re-, and de- (Fig. 4.21). The movement components of the working condyle are called pro-trusion, sur-trusion, re-trusion, and de-trusion:

- PRO-trusion: a forward direction of the movement
- SUR-trusion: an upward direction of the movement
- RE-trusion: a backward direction of the movement
- DE-trusion: a downward direction of the movement

Naturally, combinations of these movements are possible:

- PRO-DE-trusion: forward and downward direction of motion
- PRO-SUR-trusion: forward and upward direction of motion
- RE-SUR-trusion: backward and upward direction of motion
- RE-DE-trusion: backward and downward direction of motion

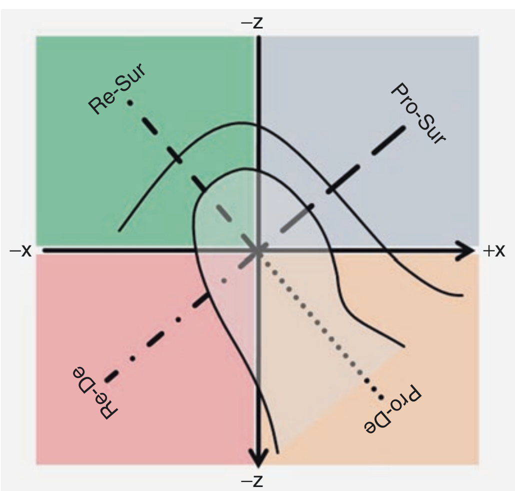

Fig. 4.21 Terminology of condylographic movements according to their direction in the sagittal plane

It should be noted that these movements and descriptions of movements are based on paths recorded using hinge axis recording techniques and they are always subject to some distortion. Due to the dimension of the condyle, especially the transversal one, it would be an improper simplification to describe only the working condyle as "rotating." If a vertical rotation axis exists exactly at the geometrical center of the condyle, around which the working condyle should rotate in a mediotrusive mandibular movement, then the lateral pole of the working condyle may also be seen to move backward and the medial pole of the condyle forward. It should also be noted that this vertical rotation axis is not stable or fixed, and that it is subject to a significant shift with the sideways movement of the mandible when it will be progressively tilted downward and outward. Consequently, there is then a backward and upward movement of the lateral pole of the working condyle, while the medial pole moves forward and downward. However, it is not assumed that the working condyle vertical rotation axis is always located at the center of the condyle: the more eccentric-median this axis is, the more distinct the PRO-, SUR-, RE-, and DE- movements will look for the lateral parts of the condyle (Fig. 4.22).

Observing the Non-Working Condyle (Mediotrusive Condyle) This condyle performs a forward, downward, and inward movement. The shape and slope of the articular fossa and articular eminence are determining factors. However, the inward movement component must be considered in even greater detail (Fig. 4.23). The inward movement path has a characteristic shape if the border movement is executed. Here, border movement is used to understand that the condyle–disc complex maintains a contact with the medial wall of the articular fossa. Since a very long time, this movement has been of great importance in gnathology and for prosthodontic reconstruction of

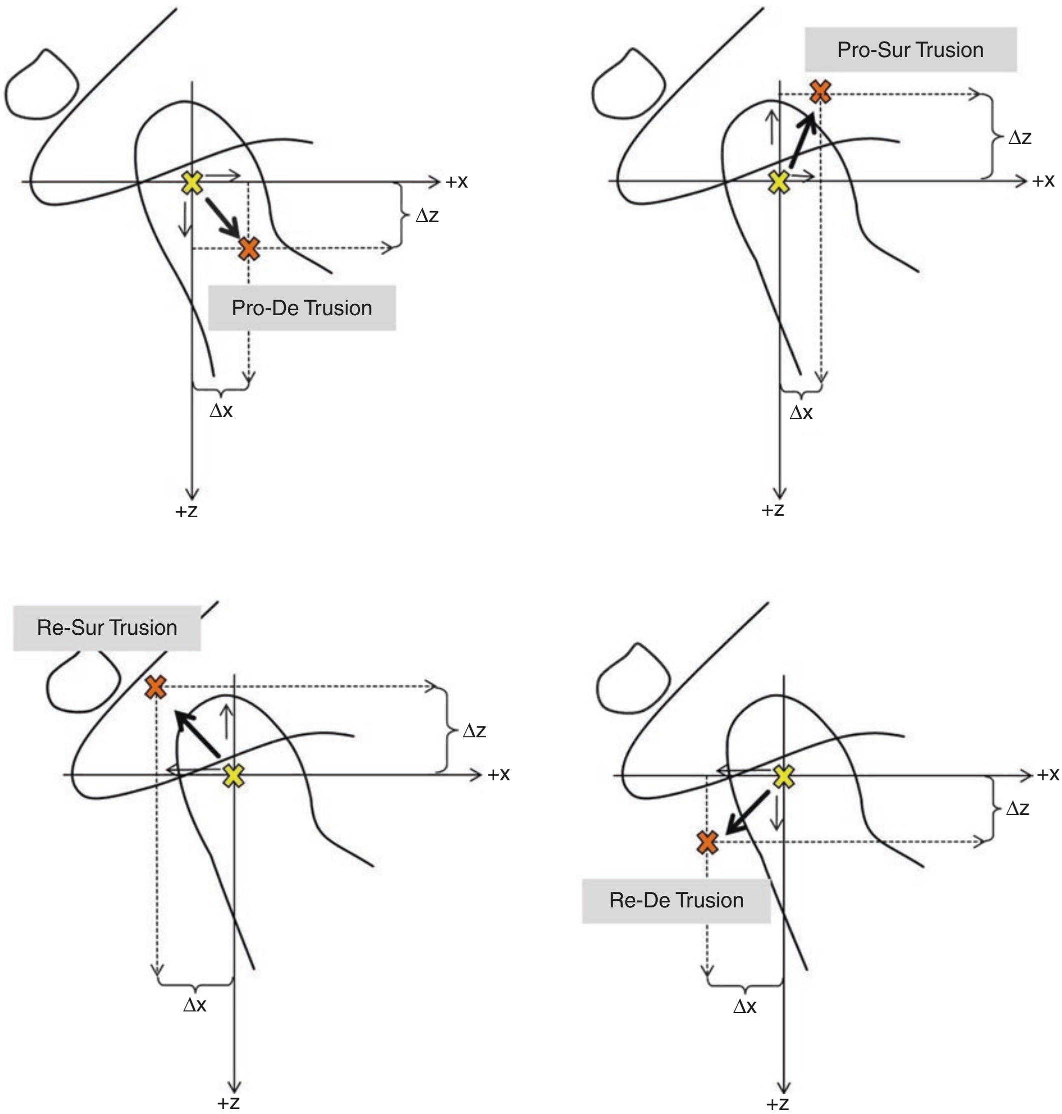

Fig. 4.22 Sagittal view—movements of the hinge axis start from the zero (where the axes meet) and are described depending on their direction of movement

occlusal surfaces. The movement was defined by Sir Norman Godfrey Bennett (1870–1947), from whom the term *Bennett movement* originated (Bennett 1908). The equivalent components of an articulator are also often referred to as Bennett elements or inserts (Fig. 4.24a–d).

The Bennett movement, which is the pronounced inward movement of the non-working condyle, influences not only the movement of the mandible, but also individual points of occlusion, particularly on the mediotrusive and the laterotrusive side. The more developed the Bennett movement, the more backward oriented are the movement paths of the cusps in the premolar and molar, which must of course be considered in reconstructive occlusal procedures.

Bennett likewise established the term *immediate side shift* (ISS) of the non-working condyle. This is described as a movement whereby the non-working condyle performs a direct inward

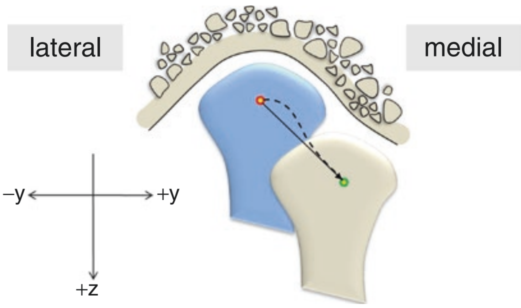

Fig. 4.23 Mediotrusion is an overall downward and inward movement (*straight line*); however, the condylographic representation of this condylar motion can be visualized as a *curve* (*curved dotted line*) which traces the border Bennett movement

motion of between 0.5 mm and 2 mm, without the essential sagittal translational (forward and down) motion (Fig. 4.25). This phenomenon has been discussed extensively in various publications, with interpretations varying considerably, from physiological to pathological joint conditions. It is becoming increasingly accepted that there is a pathological cause. Today, ISS is known as *immediate mandibular lateral translation* and is defined as follows:

> the translatory portion of lateral movement in which the non-working side condyle moves essentially straight and medially as it leaves the centric relation position (Academy of Prosthodontics 2017).

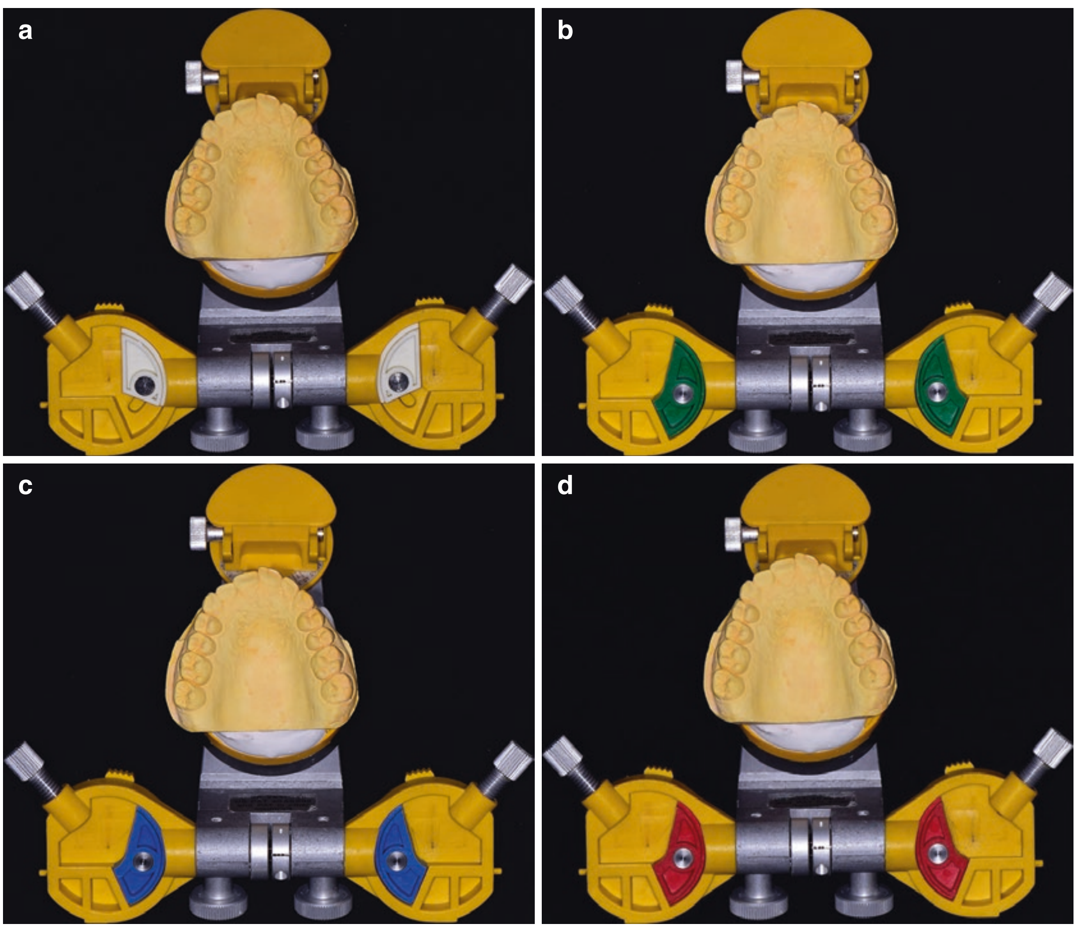

Fig. 4.24 Interchangeable mediotrusion inserts (Bennett inserts) that are commonly used for articulator programming (**a**–**d**). Not only does the shape of the path change, but its horizontal inclination can also be adjusted to fit individual characteristics that are drawn from Instrumental Functional Analysis. Not shown here is the possibility to also change the steepness and shape of the fossa/eminence part of the articulator accordingly

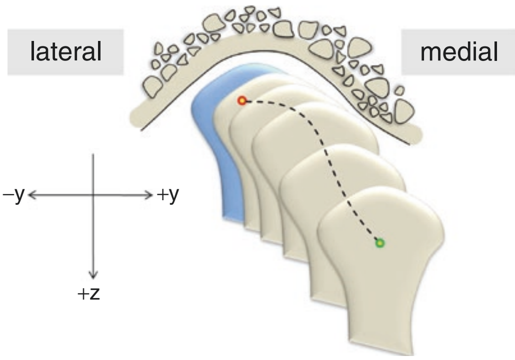

Fig. 4.25 Immediate side shift—this non-physiological feature may be noticed on the mediotrusive (non-working) condyle. Its relevance is still debated

4.2.7 Opening Movement

This is a mandibular movement from a position at which both condyles are in the fossa, then move forward along the articular eminence, with substantial mandibular rotation (Fig. 4.26). The movement path is largely determined by the articular eminence, with dental structures only having a modulating influence in the initial phase. In contrast to protrusion, a significant degree of rotation of the hinge axis occurs. Forward and downward movement is limited with increased tension in the muscles and soft tissues, giving a soft end feel under physiological conditions. A hard end feel does not occur with this motion under physiological conditions.

The determinants of this movement are:

- Articular eminence (on both sides)
- Condyle–disc complex (on both sides)

The modulators (major influential factors) of this movement are:

- Front teeth (overjet, overbite)
- Skeletal and dental asymmetry
- Shape and orientation of the condyles
- Skeletal class
- Neuromuscular system

The Posselt diagram shows a characteristic image of this motion that is largely determined by the intact structures of the temporomandibular joint (Posselt 1952, 1962). The characteristic path can only be observed where there are good ligament structures and an effective execution of the border movement during the recording: this means a movement starting with pure rotation, leading to a tightening of ligaments, with transition to combined translation and rotation (Fig. 4.27a, b).

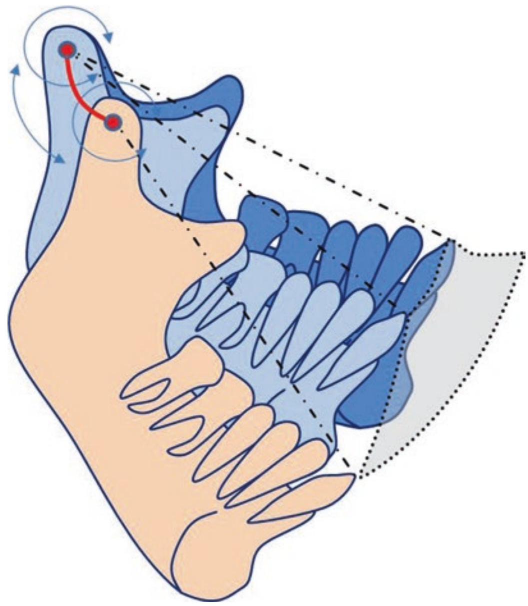

Fig. 4.26 Rotation and translation are involved in mouth opening. The effect of ligaments can be observed when looking at the changing shape of the opening movement as seen in the most posterior contour of the Posselt scheme

In condylography, when viewed from the side, TMJ movement is seen to be very simple in principle and largely consistent with the protrusion, which is due primarily to the defined trajectory of the articular eminence. Viewed from the cranial direction, and equally from the front, the physiological opening movement path is straight, showing no deviation to the side. This is a symmetrical mandibular movement.

4.2.8 Closing Movement

The closing movement of the lower jaw is typically a more or less precise reverse of the opening movement. However, it should be noted that the combination of translation and rotation can differ

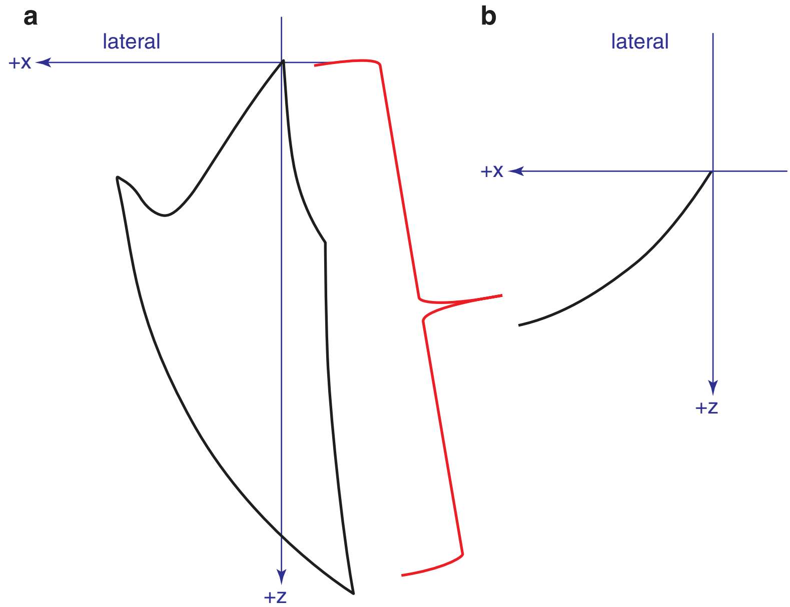

Fig. 4.27 The more posterior part of the Posselt scheme corresponds to the movement of the lower incisor during opening, with its two typical curved parts (**a**). At a joint level, the condylographic aspect of opening is a concave curve (**b**)

considerably in opening and closing, respectively. Nowadays, no explanatory models and accepted general paradigm are available to serve as a basis for detecting pathological conditions. The relevance of occlusion can be studied during the closing movement as dental structures get closer and closer. The clearer the occlusal inhibiting factors, in terms of elongated and misaligned teeth or groups of teeth, or steeply angled front teeth (i.e., deep bite or overbite), the sooner a typical movement pattern with already fully complete translational component and only pure rotation instead of closing can emerge, to achieve occlusion. As a consequence, research of a functional disorder is encouraged (Pullinger et al. 1993; Widmalm et al. 1994; LeResche 1997; Pullinger and Seligman 2000; Thilander et al. 2002; LeResche et al. 2003; Mohlin et al. 2007; Wang et al. 2009).

The closing movement is stopped at the point of occlusion, the end feel is usually hard and will be different only in case of severe periodontal disease or in some complete denture subject.

4.2.9 The Posselt Diagram

The Posselt diagram is used to describe the movements of the mandible. It was defined and its relevance shown in the 1950s and early 1960s (Posselt 1952, 1962). Usually the Posselt diagram is used to represent the movement at the lower incisor level. In most publications, it illustrates the border movements of the mandible in the lower anterior region. The diagram presents not only the lateral, frontal, and cranial, but also the three-dimensional perspective.

Naturally, similar diagrams can be presented for each point of occlusion. Condylography software makes it possible to generate individual Posselt diagrams for the individual patient.

4.2.10 The Hinge Axis

The hinge axis and the actual rotation axis of the mandible must always be considered separately. Any synonymous use of these terms is inaccurate and can lead to considerable misinterpretation. It is incorrect to equate mandibular hinge axis with the rotation axis. Due to the complex functional anatomy and biomechanics of the TMJ, mandibular motion sequences are determined by a range of interrelated axes that are also subject to spatial displacement. The mandibular hinge axis is the axis around which the mandible rotates if a pure rotation takes place in the temporomandibular joints of both sides.

It is important to consider the relation of the condyle–disc complex to the fossa, on the sagittal, vertical, and transverse planes. Determining joint centric relation has always been a central theme of function-oriented dentistry and gnathology, and still the end to scientific debate on this particular subject is not in sight. As a basic principle, however, the so-called retral, posterior, terminal, or most dorsal position of the hinge axis determines the centric relation, in case a pure rotation is being performed. At the same time, although more rarely and less consistently, the transverse centering of the condyle in the fossa is to be defined, but this is difficult to determine because of the geometric and spatial relationships involved. Nonetheless, the temporomandibular joints and the "centric" must always be seen in three-dimensional, dynamic terms. A static, two-dimensional view is at best a didactic method that must ultimately be put back into the context of a complex spatial approach. With the help of certain recording instruments (i.e., kinematic face bow), the hinge axis is determined using geometric relationships. Pure rotation of the mandible takes place around what is known as the *terminal hinge rotation* (THR). Here, the incisal edge of the lower front tooth is moved by about 15–20 mm downward and backward, corresponding to an approximate hinge axis rotation of about 12° (Fig. 4.2b). It is assumed here that the joints are correctly positioned in the transverse and vertical respects and that there is a functional and physiological relation between the condyle and disc. A translational hinge axis movement must take place for any further opening due to the tension in the ligaments (especially of the temporomandibular ligament) and capsular ligaments.

However, it would be fundamentally wrong to assume that it is possible to determine the hinge axis in every patient. In case it is not possible to determine the hinge axis, this represents a medical finding that must be documented in patient records and taken into consideration with respect to any treatment plan. Two possible strategies are briefly outlined as follows: in the first instance, attempts can be made during the initial treatment to achieve better determinability, or reproducibility, of this position. Secondly, it may be necessary to accept that the hinge axis is unstable and to establish a treatment plan based on other parameters (Sato and Kawamura 2006; Koolstra and Van Eijden 2007; Slavicek 2009).

4.2.11 DC/TMD and Condylography

In accordance to and as an advancement of the Research Diagnostic Criteria (RDC/TMD) for the use in research and science, the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) have been developed for clinical purposes (Dworkin et al. 1992, 2002a, b; John et al. 2006; Dworkin 2010; Schiffman et al. 2014). The rationale behind this is that a consistent analytic scheme for temporomandibular disorders, using medical history, anamnestic data, and clinical examination leads to the correct diagnosis. The consequent application of these decision trees leads to the following groups of diagnosis:

1. pain-related TMD, eventually in combination with headache;
2. intra-articular jaw joint dysfunctions;
3. degenerative jaw joint dysfunctions.

Within the first group, myalgia, local myalgia, myofascial pain, myofascial pain with referral and arthralgia are combined. Correlations to headaches, especially tension-type headache, are possible. The second and third group are described in the appropriate chapters within this handbook.

One task of condylography is articulator programming and transfer of relevant information to the interdisciplinary team during the design and fabrication of a new individual occlusal restoration. Moreover, condylography considerably contributes to detailed diagnostics of temporomandibular disorders. The aim of condylographic diagnostics is the differential identification of structures and functions involved in the craniomandibular dysfunction: muscles, disc and ligaments, morphological changes of the condyle. In addition, the possible influence of occlusion on the dysfunction should be illustrated by the condylographic records.

At times, assigning the pathology of a patient to only one specific category proves to be a hard task (1. pain-related TMD, eventually in combination with headache; 2. intra-articular jaw joint dysfunctions; 3. degenerative jaw joint dysfunctions). In such cases, condylography enables to better clarify the findings. Many patients suffer from a combination of muscle problems (myalgia with or without referral, myofascial pain), internal derangements (disc displacement with or without reduction), alterations of mandibular mobility (deviation, deflection, limitation), head–neck–throat pain, and degenerative changes of the condyle and/or the eminence. A problem-oriented diagnosis enables the interdisciplinary team to establish and coordinate the therapeutic procedures and to apply them in a consequent chronological sequence. The therapeutic process can be controlled accordingly to the treatment strategy, and an adequate rigorous documentation equips the team with an objective orientation and will reveal whether the treatment objectives are truly achieved.

The aim of condylographic descriptive analysis is to systematically gather and analyze all possible phenomena from a condylographic standpoint. Each individual TMJ path will be collected and then an overall picture of the condylography will be created by merging the single paths. The aim of the interpretation is to correlate the observed phenomenon in condylography with aspects from the physiological and pathophysiological function of the temporomandibular joint and its separate components.

Before starting to plan any treatment, it is imperative that all components and structures of the stomatognathic system which are responsible for the reproducible phenomenon recorded in the condylography are identified. Needless to say, these findings have to be combined with the subjective symptoms of the patient and the results of clinical and instrumental function analyses. It is therefore possible to identify causal relations early on, as functional and structural changes start to occur in the temporomandibular joint area. On this basis, therapeutic consequences can be inferred. Here are structures and functional units that are generally concerned:

- Structures
  - Neuromuscular system
  - Capsule–ligament–disc
    - Capsule and ligaments
    - Disc
  - Occlusion
  - Bony structures
- Functions
  - Chewing and swallowing
  - Phonation
  - Stress-management
  - Posture and balance

Proper assignment based on condylographic findings to one or more of the above categories is only possible with sound knowledge of the anatomy, physiology, and biomechanics of the temporomandibular joint and of all of the involved components.

Interpretation of Condylography in Relation to the Neuromuscular System When neuromuscular problems are present, a condylography is typically described as follows:

- quantity is reduced but can be increased by repeating the movement several times (warming-up phenomenon);
- quality is poor–average with a tendency to poor/very poor quality;
- descriptions of the quality of partial movements are often very different;
- descriptions of quality in the excursive and incursive movements are often very different;
- a very poor quality can lead to difficulties in evaluating characteristics;
- incursion and excursion paths are not superimposable;
- start and end points are not coincident;
- start and end points do not coincide with the reference point (Fig. 4.28).

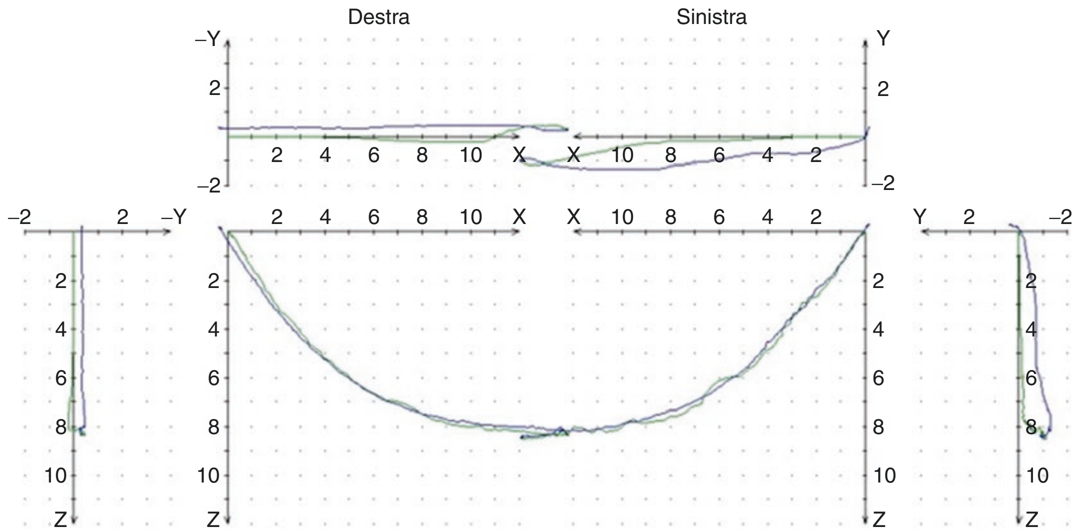

Fig. 4.28 Patient with myalgia. In this example, quality of tracing is poor; however, quantity is preserved. Start and end points do not coincide

Interpretation of Condylography in Relation to the Disc Under physiological conditions, the condyle and the disc have a very close and stable relationship that is maintained in the whole range of movement. There are only minimal position changes of the disc in relation to the condyle during movement, and these generally do not influence the condylographic recordings, or only influence them minimally, and are not included in the description of condylography.

Because of its morphology, the disc is also able to influence the position of the condyle and therefore the hinge axis. However, it can also be the case that the extremely stable relation between the disc and condyle, guaranteed by the lateral ligaments and the joint capsule, is loosened. The condyle will then be able to leave the thinner central part of the discus and be positioned permanently, or even just temporarily, on the thicker posterior edge. In condylography, this can lead to clear, typical phenomena:

- changing characteristic of the tracing;
- initial convexity, if the hinge axis is determined with a dorsal "drive" during hinge axis location;
- hypermobility, the quantity is increased;
- separation of excursion and incursion tracings;
- early or complete separation between the superimposed tracings of protrusion and mediotrusion;
- clear influenceability with manipulation;
- immediate side shift—spontaneous or triggered;
- signals in the recording indicating disc displacement with reduction;
- typical condylography characteristics indicating disc displacement without reduction.

Typical Findings in Condylography with an Unstable Relation Between Disc and Condyle The correct technique to locate the hinge axis and perform a centric registration is still discussed with extreme controversy. The concept of the centric relation is however a central element in daily clinical dentistry. There is a daily need to determine lower jaw positions which can be reproduced and are not determined by dental structures (Orthlieb et al. 2011). Various ideas and schools of thought have established themselves regarding the right technology to use when determining centric relation. This however has led to confusion, doubt, and ultimately resignation because of the variety of overlapping and unclear definitions (Slavicek et al. 1983). Nevertheless, a disc displacement with reduction (DDwR), clinically called a "reciprocal click," will show a typical tracing in condylography (*crossing signal*). In such condition, the disc is not in the physiological position in centric relation but is mostly shifted forward and inward—in front of the condyle, during the opening movement. During protrusion and mediotrusion, a repositioning of the disc takes place, the functional condyle–disc unit is restored, and the disc will now remain in place during the rest of excursion and during part of incursion. Only just before reaching centric relation, a displacement will take place again—the disc and condyle lose their physiological relation (Figs. 4.29a–f and 4.30a, b). On the other hand, a disc displacement without reduction (DDWoR), clinically noiseless, is presented by a typical tracing in condylography as well. At rest, the disc is not in the physiological position in centric relation but dislocated forward and inward—in front of the condyle. In the case of the protrusion movement and mediotrusion, there is no restoration of the disc–condyle unit during the overall excursive and incursive movement. The movement is reduced in quantity, and the characteristic of the tracing is straight but it may show some convex-

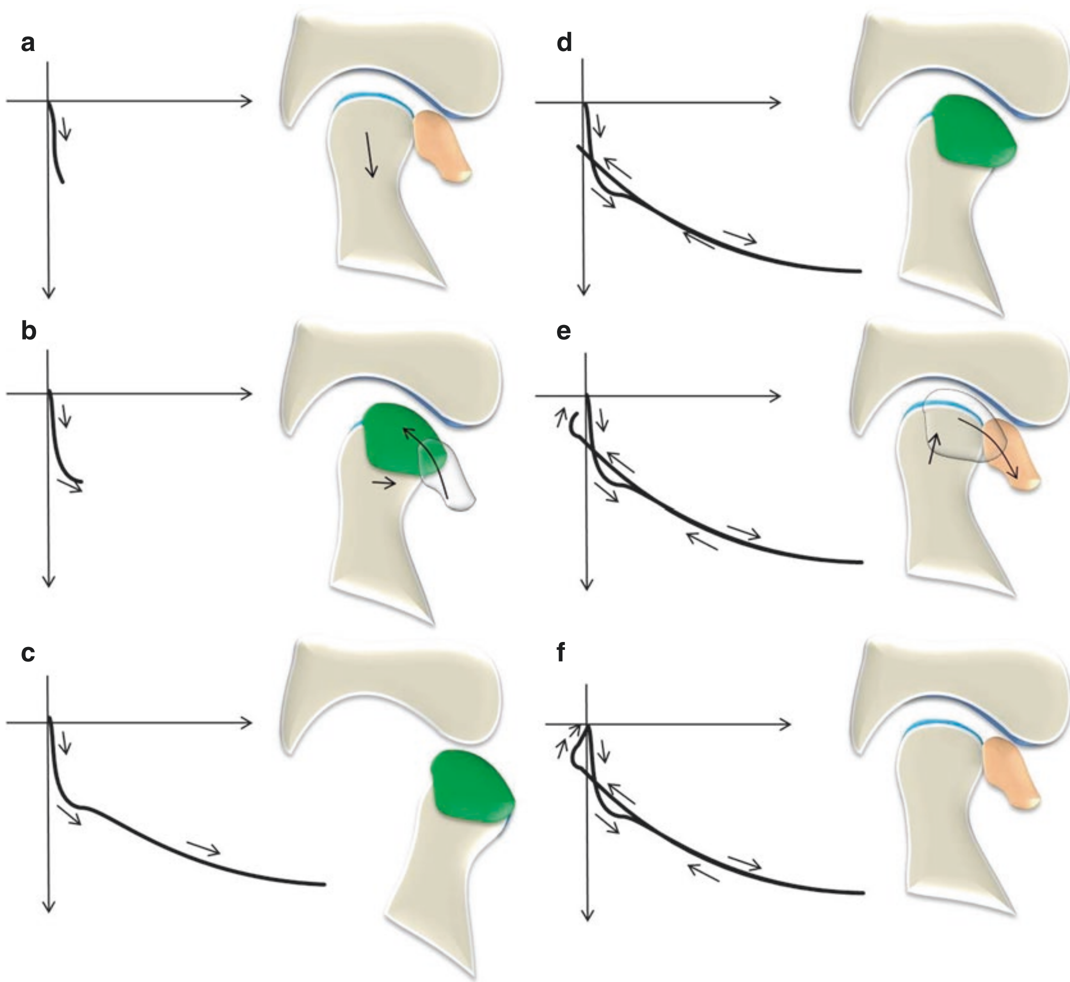

Fig. 4.29 (**a**–**f**) Condylographic sign of DDwR (*reciprocal click* or *crossing signal*). Reduction is seen in (**b**). Disc displacement occurs again in (**e**)

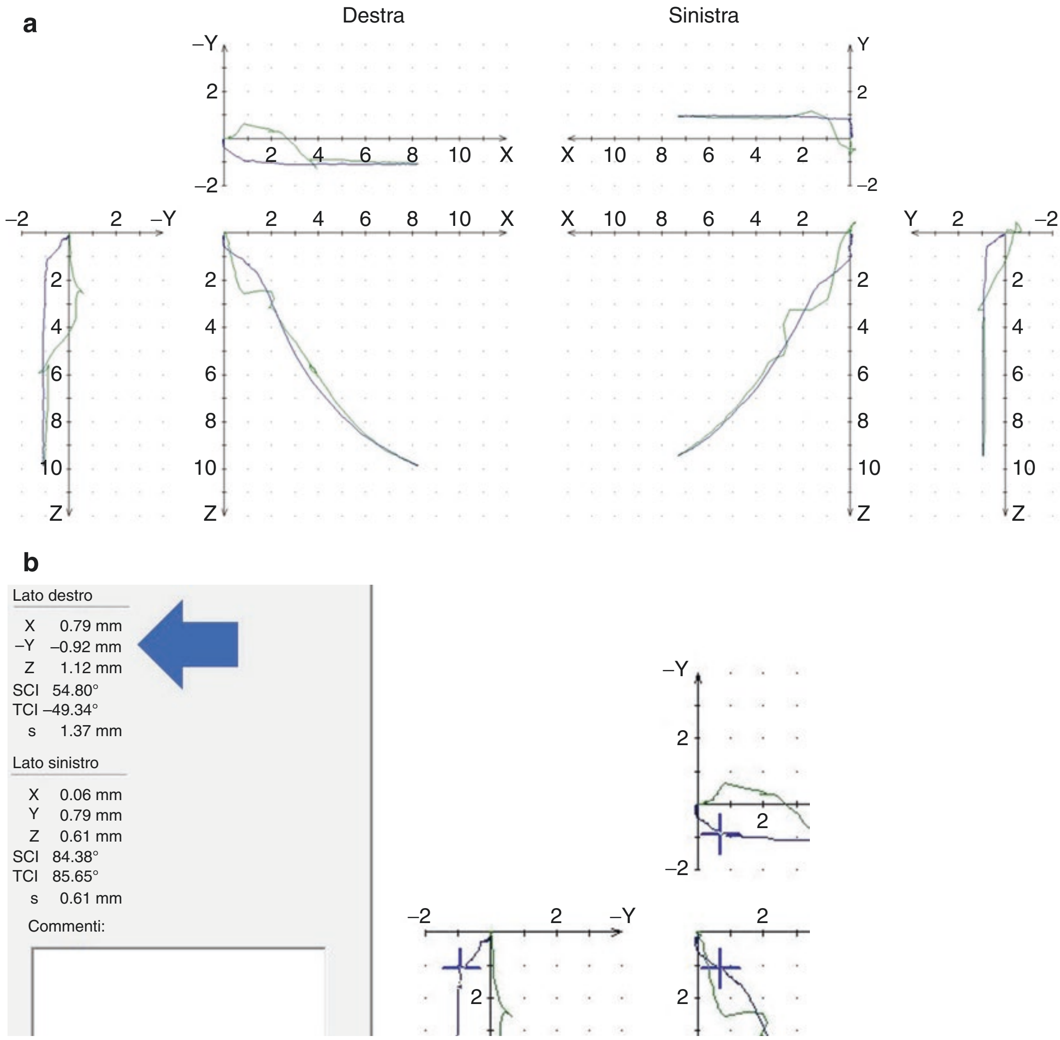

Fig. 4.30 (**a**, **b**) Bilateral DDwR as seen on a real condylographic tracing. Protrusion–retrusion is here displayed (**a**). Close-up of the first part of the same tracing (right side) is seen in (**b**). The cursor (+) is placed where the second click (closing click) takes place. Xyz coordinates are given by the software and can be used in the articulator for diagnostic/therapeutic purposes as these are the spatial points where disc displacement is about to occur again during closing

ity, especially in the case of a chronic displacement (Figs. 4.31a–d and 4.32). Unlike the acute joint block, in chronic locked joints the patient mostly indicates no pain, both in a relaxed state and when the lower jaw is moving.

The system used in Fig. 4.12, 4.28, 4.30 and 4.32 is CADIAX (GAMMA Medizinisch-wissenschaftliche Fortbildungs-GmbH, Austria) The articulator displayed in Fig. 4.24 is SAM 2P (SAM Präzisionstechnik, Germany)

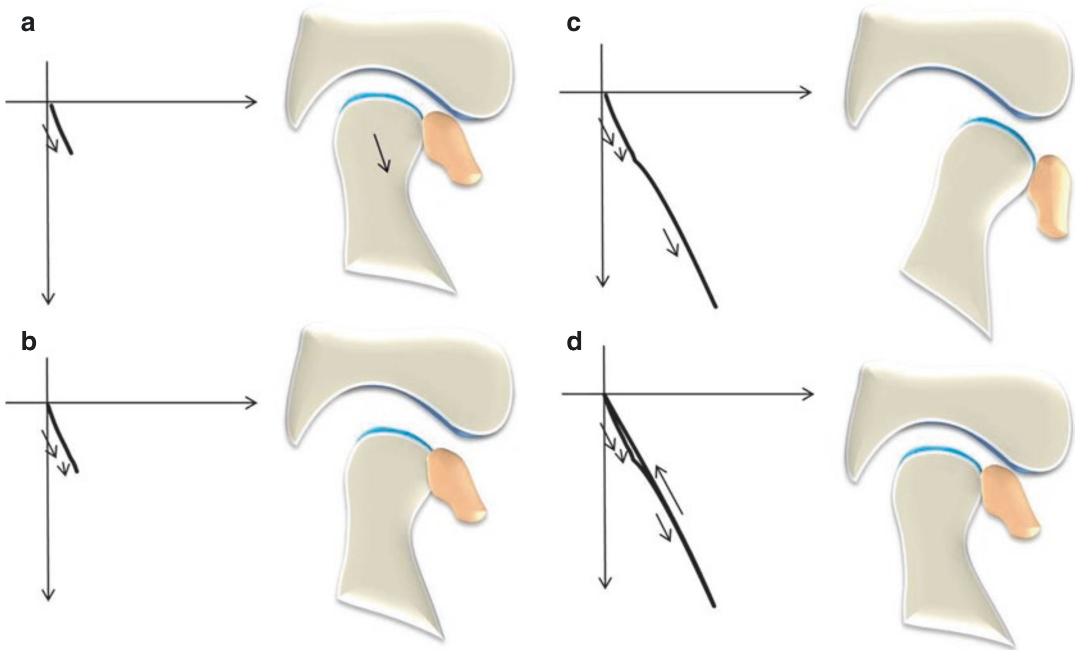

Fig. 4.31 (**a–d**) Condylographic sign of DDWoR (straight characteristic) with reduced quantity, a trait which is especially visible in patients with acute closed lock

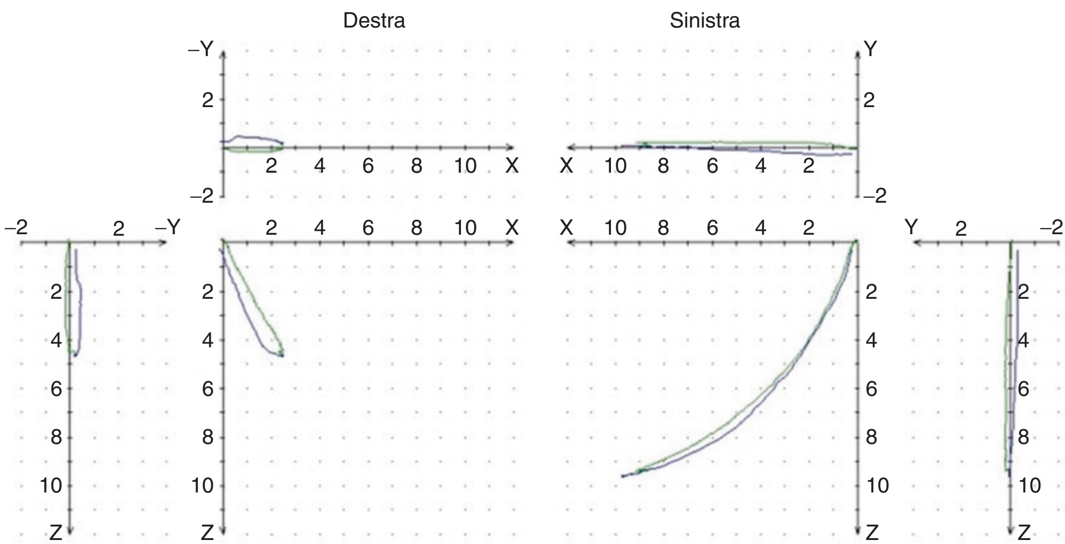

Fig. 4.32 Right side DDWoR (acute) as seen on a real condylographic tracing—protrusion–retraction is here displayed. The right side has a straight characteristic with a reduced quantity

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