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Original Research Article

Occlusion trajectory and a concept of a device for testing operating life of dentures

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A R T I C L E I N F O

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A B S T R A C T

Purpose: This paper presents an original method for the assessment of occlusion trajectory. On this basis, a special device for the assessment of operating life of dentures was designed.
Material/methods: For this purpose, the SMART system by BTS for a comprehensive movement analysis was used. In order to analyze occlusion trajectory, characteristic points on patients' heads were appointed in which markers were placed, in accordance with the rules of measurement in dentistry. Markers' movement was recorded by means of 6 cameras, and then composition of coordinates was performed in a 3D system.
Results: In this way, curves representing movements of the characteristic points were plotted which, after the composition, with a considerable approximation, can be regarded as occlusion trajectory.
Conclusions: On the basis of the obtained results, a thesis was put forward to the effect that traditional tribological testing machines based on systems of the pin-on-disc, ball-on-disc, etc. types, due to the simplicity of their working movements, are not adequately precise for the purpose of operational assessment of elements of prosthodontics. On this basis, a tribological node for a specialist testing machine for the assessment of operating life of dentures was designed.

1. Introduction

The anatomical structure consisting of the temporomandibular joints and the mastication muscles acting together, which comprise the stomatognathic system, constitute the complex process of mandibular (the movable bone) movements in relation to the maxilla (the immovable bone). These movements are performed in three key directions [1,2]:

– opening and closing (lowering and lifting)
– antero-posterior (protrusion and retrusion)
– lateral mandibular movements (right and left).

Moreover, the net action of the movements mentioned above is not only a rather vital but also possibly the most important aspect. In this context, it can be stated that during mandibular movements, individual elements in the temporomandibular joints and the muscles participating in the act of mastication work together closely. The initial position of the mandible is its rest (postural) position, in which the mandible is slightly distant from the maxilla, while the adductor and the abductor muscles are in equilibrium with each other [3]. During the lowering movement, translation occurs in the joint, i.e. the downward movement, protrusion, and rotation of the articular head–movement around the transversal axis of rotation [3]. Working is the digastrics muscles, the mylohyoid muscles, and the geniohyoid muscles, the movement in both joints being symmetrical. During the lifting movement of the mandible, the temporal muscles, the masseter muscles, and the medial pterygoid muscles are working, the movement being a reverse of the lowering movement. In the final phase, all teeth are in their maximal intercuspal position. Protrusion should also be a symmetrical movement, in which the condyle of mandible moves forwards and downwards to the vertex of the articular eminence. Acting bilaterally in this movement is the lateral pterygoid muscle, while retrusion is caused by the temporal muscle, the masseter muscle, and the muscles of the floor of the oral cavity. During lateral mandibular

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movements, the situations in each of the joints on the acting side (towards which the movement tends) and on the balancing side are different. Different are also the muscles acting on both sides. The result of this whole situation is that the kinematics of movement in the stomatognathic system, in relation to a selected point, becomes rather complex, especially in connection with the movement of the counterpart (e.g. an opposite tooth). Interference and interaction between individual muscle groups takes place, as well as composition of forces and their directions [4]. The result of this fact is that, in a research sense, novel construction solutions for tribological machines that would reflect, as closely as possible, the kinematics of movements during mastication are constantly sought for. This pertains to an analysis of tribological and operational properties of dental materials. As of now, used for this purpose are pin-on-disc machines [5,6], with simple kinematics at a rotational or reverse disc movement, and a homogeneous or cyclic unit pressure of the pin. As such, the testing machines are generally recognized as acceptable in research of this kind throughout the world; however, this is in fact a major simplification of the situation described above. Furthermore, literature provides scant information on the matter of occlusion trajectory, or real-life kinematics of movements in a stomatognathic system translated into graphical or mathematical descriptions. Hence, this paper attempts to provide a model description of occlusion trajectory, which became the basis for designing and building a specialist testing machine for assessing operating life of dentures.

The main aim of this study was to demonstrate the need for construction of equipment to assess the service life of dentures, with the kinematic node characterized by the complexity of movements that occur during mastication [7,8]. To demonstrate that complexity, the SMART system was used and it was about a qualitative assessment only. Thus a comparative analysis with other methods was omitted. Demonstrated qualitatively the complexity of movements (using SMART) allowed to build a camera that, in its construction, is much better and makes it possible to model more complex movements in relation to traditional testers of pin on disc type.

2. Materials and methods

2.1. SMART system

For the purpose of the tests, a non-invasive system for a comprehensive movement analysis was used, i.e. SMART by BTS. Systems of this type are used for tasks such as: analysis of human walking [9], recognition of human emotions [10], animation of human movement [11], robotics [12], or sports [13]. Possibilities of this type of systems are not limited only to the movements performed within the frame of large joints of the human body. And so in [14] Vicon optical system was used which consists of 13 cameras, among others, to record the movements of fingers of the subjects. The resulting measurements allowed the motion animation with fingers, while maintaining adequate to the performed action, natural movements. On the other hand, in [15] the motion capture system has been used for the analysis of the facial movement.

The SMART system, used for the present tests, is equipped with 6 IR cameras recording images with a frequency of 60 Hz. During operation, the cameras emit infrared radiation which, after reflecting from passive markers placed on the tested person, enables a reconstruction of the trajectory of movement of these markers in 3D. According to the manufacturer, the reconstruction error of the spatial position of the marker is <0.4 mm. Through modelling, markers' movements allow to determine the movement of the tested person. These characteristics were used for the analysis of mandibular movements in relation to an immovable mandible, the trajectory of movement being determined by choosing characteristic points appointed on the skin of the patients' heads, i.e. the trichion, the gnathion, and the zygion.

2.2. Model description

For the purpose of a recording of the mastication process by means of the SMART system, a model consisting of 4 markers was designed, whose placement corresponded to the aforementioned points. The method for fixing these points is presented in Fig. 1. The trichion point was marked as CZ; the gnathion as BR; the left zygion as LKP; the right zygion as RKP (Fig. 1).

The CZ, LKP, and RKP markers were used to create a coordinate system connected with the head of the tested person (HEAD). Due to the generally known system of three characteristic planes: sagittal, Frankfurt, and orbital, a very similar system of three axes of the coordinate system was created. The transversal axis was defined as a connection of LKP and RKP points. Half the distance between LKP and RKP points determined along the transversal axis describes the MKP point, which defines the origin of the HEAD coordinate system. The longitudinal axis was defined by connecting MKP and CZ points. The sagittal axis was defined as an axis perpendicular to the two axes leading through LKP and RKP points as well as MKP and CZ. The method for defining the axes is illustrated in Fig. 1.

The trajectory of movement of the BR marker was shown in a local coordinate system, owing to which a model thus defined enabled a recording of the following movements performed during mastication (the first quantity occurs for positive values):

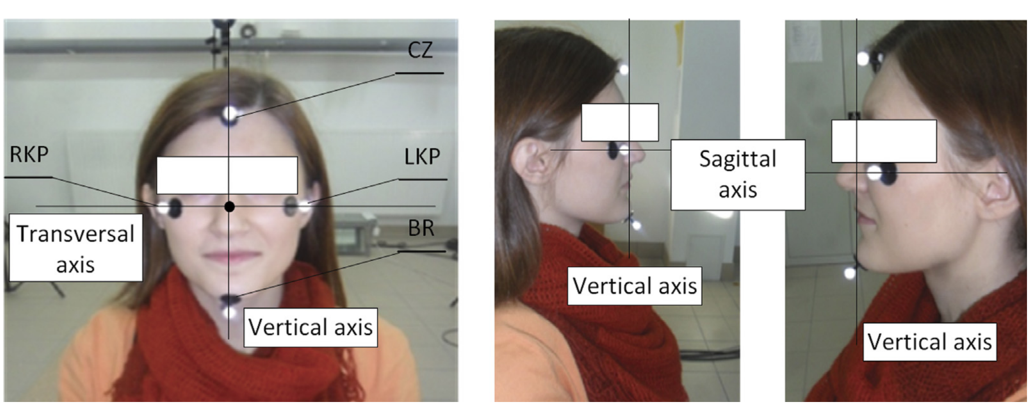

Fig. 1. Method and placement of markers on the patients' head.

- closing–opening of the mandible along the vertical axis;
- left–right movement along the transversal axis;
- protrusion–retrusion along the sagittal axis.

Placing the markers on the face of the tested person has a critical impact on the accuracy of the presented model. The necessity to create the LKP – RKP line parallel to the line of eyes of the tested person is highly problematic, in addition to LKP and CZ as well as RKP and CZ being defined by vectors parallel to the vertical axis of the head.

2.3. Investigation procedure

The tests were carried out at Bialystok University of Technology. 7 persons (5 female, 2 male) participated in the tests. Before starting the experiment, the tested persons were informed about the aim and the methodology of the research. All the persons gave their consent to take part in the research. In the course of the tests, 2 measurements were performed: the first one was static, i.e. the person was sitting still (not masticating); the second one – during mastication. For the tests in a cycle of mastication, a traditional chewing gum was used. The aim of the first measurement was to determine the initial position (closed mandible) and establish measurement errors. These could result from:

– the system (errors in the identification of marker position, errors in 3D reconstruction);
– the model (the problem of determining the midpoint of a segment between the cheekbones);
– the accuracy of marker sticking (if correct axes failed to be maintained).

The aim of the second measurement was to combine movements of the markers, taking into consideration data from the static measurement, and on this basis to finally determine the occlusion trajectory during the act of mastication.

3. Results

Example curves of the determined marker movement for one of the chosen persons are shown below. Fig. 2 illustrates the signals received from the markers during a static cycle. As it turns out, slight movements of markers in the idle state were recorded. This results from involuntary and unconscious movements of the tested person. It can also be added that, for a better imaging of this phase, the duration of a measurement in a static state was 6 s, which probably caused the movements of markers. At the same time, it can be observed that slight errors during the 6 s measurement indicate that the model was implemented correctly and the results of the model are reliable. On the basis of the graphs presented below, the point $X = -8$ mm, $Y = -77$ mm, $Z = -33$ mm was adapted as the initial position of the mandible for the person in question. During the dynamic measurement, the tested person was chewing gum in a casual manner. The duration of the measurement of mastication was approx. 10 s, owing to which several cycles for the same person were obtained. After discarding the first 3 cycles, the remaining ones were reduced to the duration of a single cycle (from 0 to 100% of a cycle of mastication with steps of 1% s) and averaged.

After performing a series of tests, their results were processed. The obtained curves and the nature of movements differed from one another (in relation to individual persons). This may mean that finding an unambiguous occlusion trajectory is only possible through statistical processing and approximation of measurements performed on a chosen and adequately selected human population. It should also be remembered that slight differences in the obtained results may result from typical errors of the measuring equipment, the method of measurement, etc., which occur in any test and measurement and cannot be avoided.

Fig. 3 shows an example curve of BR marker movement during a single averaged cycle. Fig. 3a pertains to a situation in which a marker moves left and right (looking straight at the tested person). The data shows that during mastication the marker changes its

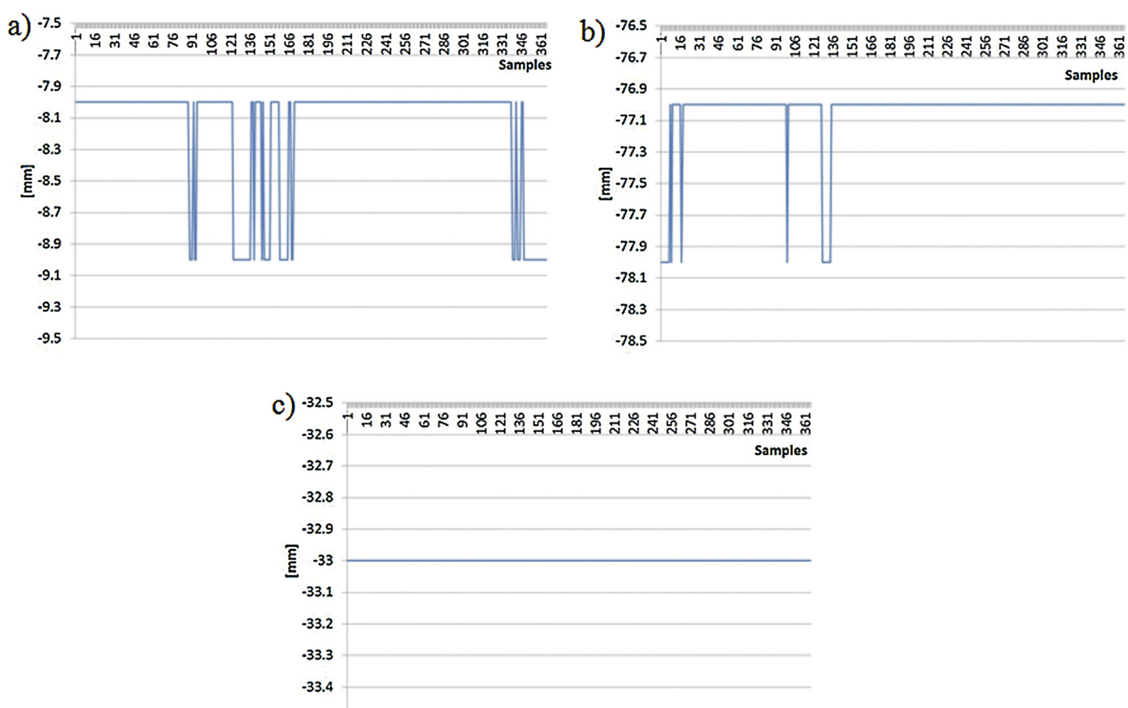

Fig. 2. Movement of the BR marker in static along the following axes: (a) transversal, (b) vertical, (c) sagittal; (the horizontal axis: time in [s], the vertical axis: marker position in the local coordinate system in [mm]).

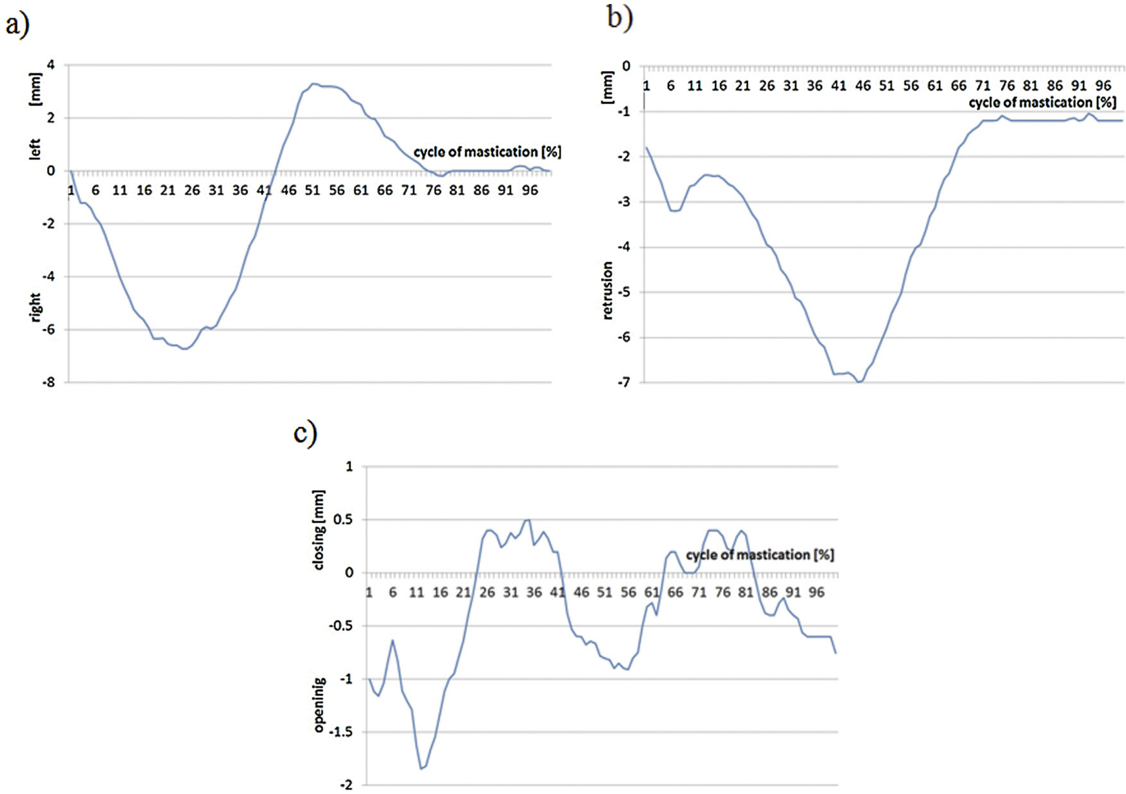

Fig. 3. Movement of the BR marker during a cycle of mastication along the following axes: (a) transversal, (b) vertical, (c) sagittal; (the horizontal axis: percentage of a cycle of mastication, in [%], the vertical axis: movement, in [mm]).

position from the left to the right side (and the other way around), passing through the "0" point, which seems rather obvious, there being no symmetry of movements.

Fig. 3b is connected with the upwards-downwards movements. In this case, the marker moves downwards (during mastication), after which it returns to the "0" position, staying at a distance of approx. 1 mm from the rest position. This difference is most probably caused by the presence of the chewing gum, which lingers between the teeth. Fig. 3c is connected with protrusion and retrusion of the mandible. This movement is asymmetrical with a visible residual movement backwards, which may be a result of the movement of individual antagonistic teeth in relation to each other, and their surfaces of a diverse geometry.

After processing the results for the individual axes, a composition of the results was performed in order to obtain trajectories for complex movements.

Fig. 4 presents a composition of movements of the markers in relation to two axes; Figs. 5 and 6, in relation to three axes.

The obtained results clearly indicate a co-dependency of movements in relation to the axes of the introduced coordinate system. For example, Fig. 4a shows that the marker changes its position from the left to the right side with a simultaneous movement downwards and then upwards. Fig. 5 shows that during a single cycle of mastication, there is a change of marker position from the left to the right side with its simultaneous lowering and lifting, and a protrusion and retrusion of the mandible. The same

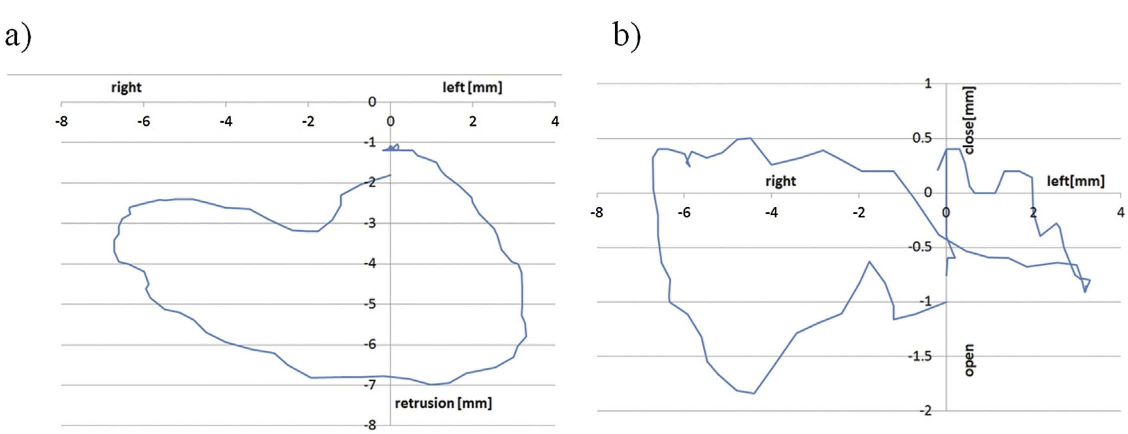

Fig. 4. Trajectory of the BR marker – a composition of movements: (a) transversal axis/vertical axis, (b) transversal axis/sagittal axis (movements in both axes in [mm]).

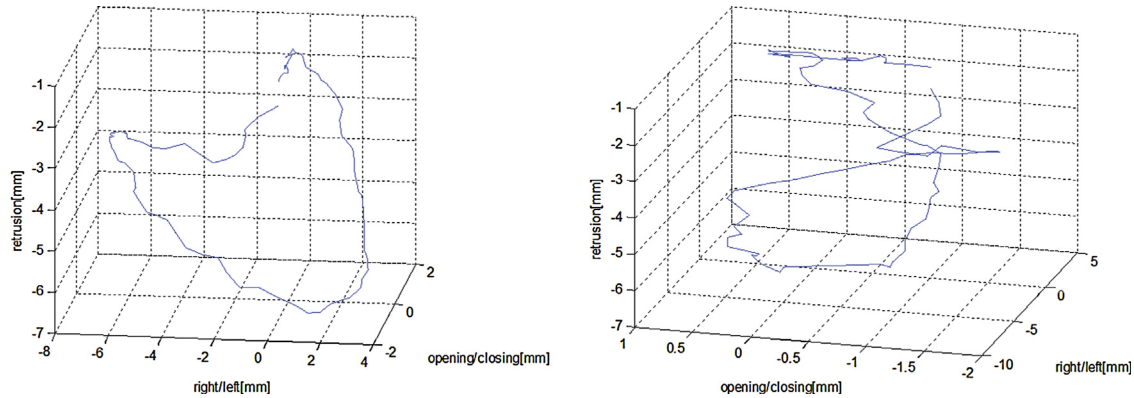

Fig. 5. Trajectory of the BR marker – composition of movements in three axes (one cycle of mastication, movements in [mm]).

relationships are indicated in Fig. 6. The main result of the conducted analyses is the experimental proof (regardless of the accuracy of measurement) that what we deal with during mastication is a complex movement. A detailed analysis of trajectory curvatures was omitted at this stage. It was assumed that what we dealt with was a complex movement in three axes. A point lying on the trajectory describes an arc whose shape is close to an ellipsis or a parabola. Within a single cycle the arc rises and falls, which may acquire diverse forms (linear, step, etc.), asymmetrically in relation to the adapted coordinate system. The asymmetry is probably connected with left- or right-sided occlusion, while in special cases we may be dealing with a two-sided occlusion.

4. Discussion

In the sense of experimental research in the area of orthotic designs and materials, this means that using simple tribological tester machines should be only regarded as a substitute, considerably simplified means of their assessment and selection.

Addressing the methodology of experimental research, it seems obvious that in order to assess the usefulness of a certain element for certain applications, and when carrying out laboratory tests, real-life operating conditions of a given element should be reflected as closely as possible (both in the sense of external inductions and the kinematics of its movements). In this context, attention is paid to the kinematics of operation of traditional tribological testers, which are based on the pin-on-disc, ball-on-disc, etc. type systems. Their kinematics of operation, although extremely useful in numerous research studies, seems of little effectiveness in the case of the materials used in prosthodontics.

In this context, this paper presents the scheme of a friction node of an original tribological testing machine for the assessment of operating life of dentures. The testing machine in question was designed considering the issues of a complex occlusion trajectory described above. It should be added that a device based on these assumption was built in the Department of Materials Engineering at the Faculty of Mechanical Engineering of Bialystok University of Technology. The design of the device is patent protected, due to which this paper presents only a simplified friction node of the device, together with its capabilities for movements and loads (Fig. 7). The designed device is assumed to be of use in the assessment of both crown type single-part fixed dentures and bridge type multi-part ones, as well as partial and complete removable dentures. Fig. 7a illustrates the view of a friction node of the device in the lateral position. This projection shows the movement (upwards-downwards) of the loading pins in the vertical plane. There can be three or more loading pins (optionally). Fig. 7b and c illustrates the arrangement of pins and the full range of the designed movements of the working elements. Owing to the fact that the working pins are driven by a special mechanism, their movement is phase shifted, which creates a "wave" effect. In Fig. 7b and c, the swinging motion of the bottom table in relation to the horizontal plane is marked.

At the same time, the bottom table has the possibility of a lateral motion (right–left), as well as of lifting and lowering. A normal device operation will combine all these movements, which

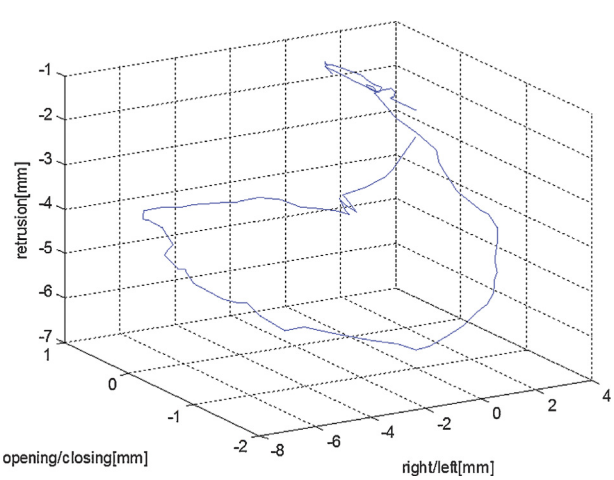

Fig. 6. Trajectory of the BR marker – a composition of movements in three axes (one cycle of mastication, movements in [mm]).

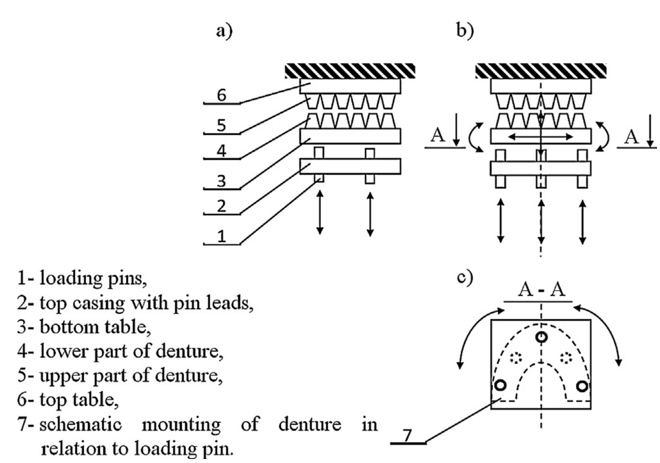

Fig. 7. The working node of the device for the assessment of operating life of elements of prosthodontics: (a) lateral view, (b) rear view, (c) A-A cross-section (arrows indicate the possibilities of movement and their folded in any combination).

will cause the tested elements to perform complex movements – sinusoidal, both along and across the tables.

Optionally, a possibility of disassembly of the bottom table is allowed for, in the event of a necessity of an assessment of individual crown-type elements or permanent dental fillings. In such cases, the tested sample is mounted to the top table opposite the loading pin and the device is switched on.

Another important aspect is the possibility to choose the number of pins, from a minimum of 1 to a maximum of 5 pins. The initial situation assumes that three pins are used; however, if there is a need, an arrangement of 5 pins can be used, as shown in Fig. 7c. Obviously, there is also a possibility of changing the arrangement of pins depending on the size of dentures.

In relation to parameters of external inductions, it should be noted that the load of the tested samples will be controlled through an appropriate setting of the top table; while the number of cycles of the working pins, through the rotational speed of the electric motor and the time of device operation.

It is assumed that the operation of the testing machine will allow to measure the maximum loading force. Apart from the loading force, a measurement of friction forces between the cooperating elements is expected, a generalized friction force being used in the analysis – as the net force of all the component friction forces. The tests can be carried out either within a specific time period or until first damage of any type to the assessed elements appears. It is also expected that the quality of the tested dentures will be determined by computing coefficients of reliability, macro- and microscopic examination, or tribological indicators.

It should be added that the whole of the working system will be housed in a transparent chamber with appropriate connection pipes, through which the confounding medium, such as for example tobacco smoke, will be pumped. Liquids such as alcohol, tea, coffee, or artificial saliva will be applied with the use of the droplet method or in an aerosol form. Additionally, the system will be heated up to a temperature of 37 °C in order to reflect the conditions in the oral cavity as closely as possible.

A testing machine thus designed gives a good approximation (in relation to the kinematics of movement of the working elements, as well as the micro- and macro-environment) of the operation of elements of prosthodontics in real-life conditions of mastication in the oral cavity. At the same time, the application of media of various kinds will allow to assess their influence on the reliability of the tested elements, but most importantly being essential for modelling a real-life "microclimate" of the oral cavity.

5. Conclusions

The paper presents a proposal for a method of assessment of occlusion trajectory during mastication. The SMART system was used for the test, and an assistance of seven volunteers was obtained. The performed tests allowed to build a trajectory of movements of markers placed in characteristic spots on the head. A 3D composition of the obtained individual movement curves was performed, which resulted in obtaining a signal that was a composite of movements in the three adapted axes. The 3D graphs thus created allowed to formulate the following general conclusions:

1. During the process of mastication, in this particular case, we deal with complex movements in three axes. It should be added that all three movements (along the *X*, *Y* and *Z* axes) occur simultaneously. This movement is characterized by an asymmetry in relation to the adapted coordinate system, while the obtained curvatures are similar in shape to sections of an ellipsis or a parabola (however, a detailed analysis of these shapes was omitted).
2. On the basis of the obtained results, a thesis was put forward to the effect that traditional tribological testing machines based on systems of the pin-on-disc, ball-on-disc, etc. types, due to the simplicity of their working movements, are not adequately precise for the purpose of operational assessment of elements of prosthodontics. It is believed that using traditional tribological testers is adequate for qualitative comparison of dental materials with each other and in relation to other alternative materials. These tests, however, do not reflect real states of external inductions in the oral cavity. Furthermore, designs of traditional testing machines do not allow for an assessment of the whole orthotic construction, but rather of a single element only. In this sense, there appears a necessity for the design of a testing machine that would reflect the kinematics of movement and the microclimate of the oral cavity as closely as possible, and make it possible to test whole orthotic constructions. Only then can more substantial assumptions on the operational quality of elements of prosthodontics elements be made.
3. On the basis of the measurements performed during the act of mastication, a kinematic scheme of a friction node of a tribological testing machine for the assessment of operating life of dentures was proposed. The design of such a testing machine reflects the kinematics of movement during a real-life cycle of mastication in the human oral cavity in a more accurate manner (in comparison to traditional testing machines). In addition, it provides a simulation of the microclimate of the oral cavity.

Conflict of interests

The authors declare no conflict of interests.

Financial disclosure

None declared.

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