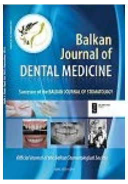
Mathematical calculation of the occlusal plane and fabrication of complete dentures using the Staub Cranial System



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Abstract:

Background/Aim: For the fabrication of a removable partial or a complete denture, it is important to reestablish the patient's individual occlusal plane and the vertical dimension of occlusion (VDO). Several methods have been described in the literature to determine the VDO for patients with complete dentures. For this purpose, in the early 1980s, Staub developed a software and a special series of appliances, the so-called Staub Cranial Analysis and Fabrication System for the fabrication of removable dentures as well as for the analysis of casts and existing dentures. The Staub Cranial System is based on defined anatomical reference points on the jaw model. According to Staub, these points should be present on every cast and unchangeable in their position. They are supposed to enable an exact indication of the former position of the natural teeth in a partially or edentulous jaw. **Case Report:** This paper analyzes the basic principles of Staub Cranial Analysis and presents the clinical application in a clinical case of a fully edentulous patient with initial not satisfactory prostheses. The paper describes in detail the step-by-step analysis process and the artificial teeth arrangement leading to a pleasing and natural set of dentures that anatomically fit in the stomatognathic system of the patient. **Conclusions:** New diagnostic possibilities, e.g. in orthodontics, prosthetic reconstructions, and implantology, could be implemented using this system. It also could be integrated in digital workflows for complete denture fabrication.

Keywords: complete denture; dental occlusion; occlusal plane; vertical dimension

INTRODUCTION

For the fabrication of a removable partial or a complete denture, it is important to reestablish the patient's individual occlusal plane and the vertical dimension of occlusion (VDO). Several methods have been described in the literature to determine the VDO for patients with complete dentures [1]. For this purpose, in the early 1980s, Staub developed a software and a special series of appliances, the so-called *Staub Cranial Analysis and Fabrication System* for the fabrication of removable dentures as well as for the analysis of casts and existing dentures. - The Staub Cranial System is based on defined anatomical reference points on the jaw model. According to Staub, these points should be present on every cast and unchangeable in their position. The points are supposed to enable an exact indication of the former position of the natural teeth in a partially or edentulous jaw.

A total of four points (right direction point A and left direction point B, anterior induction point C and posterior induction point C_1) and two lines (left conclusion line CL and right conclusion line CR) are identified in the maxilla. The direction points are determined as follows: The deformed areas of the pterygoid hamulus and part of the pterygomandibular raphe are marked with a pencil line by placing an extended pencil lead on the maxillary cast parallel to the horizontal plane. This line is then carefully traced with the pencil. Finally, the intersection point of the resulting change in direction is marked with a transversal line and labelled A (right side) or B (left side) (Figure 1) [2][3]. The dentist or the dental technician should consider that the direction points A and B are not always located at the lowest point behind the maxillary tuberosities, but they are mirror images of each other across the median axis of the maxilla [4].

The induction point C_1 is defined as the intersection of the posterior outline of the incisive papilla with the median axis of the maxilla. This is also considered a topographically stable point [4][5]. It is said to form an equilateral triangle with the two direction points A and B [4].

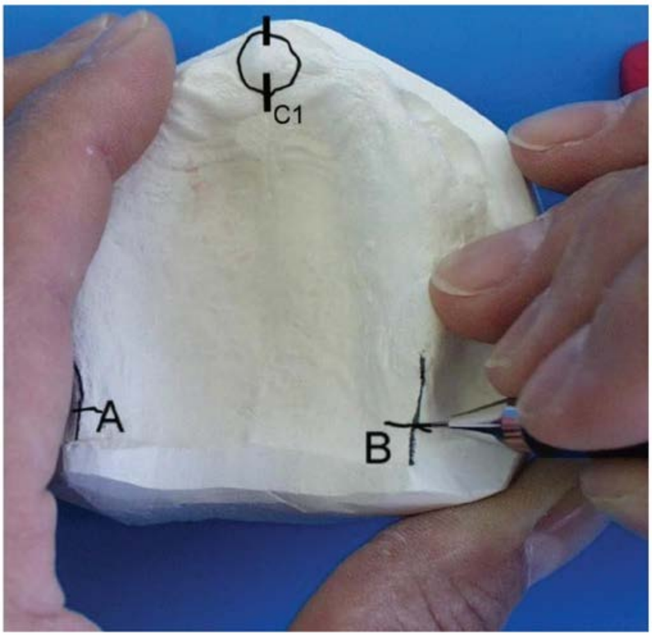

Figure 1.
Manual determination of direction points A and B

The induction point C is the intersection of the anterior outline of the incisive papilla with the median axis of the maxilla. In contrast to C_1, point C can be individually variable in its position and lie outside the median axis. In such a case, the point is transferred to the median axis by drawing a circle around the posterior induction point C_1 with the radius C_1C. Point P is defined as the center of incisive papilla (Figure 2).

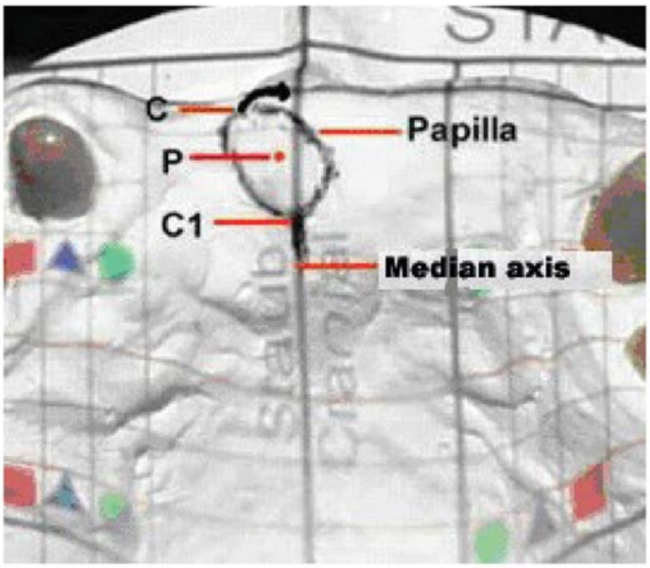

Figure 2.
Transfer of point C on the median axis

The conclusion line is determined as follows (using the right conclusion line as an example): The lead pencil is inserted into the fold to the right of the labial frenulum, coming from the alveolar ridge. This procedure is repeated several times until a change in the direction of the curve traced by the pencil is noticed. This change is marked with a transverse line. Following the same procedure, several lines are drawn 3 to 5 mm distal to the mesial line. The change in direction is always marked with a transverse line. The connection of all lines, which should be at the same level, results in the right conclusion line. The same procedure is used to determine the left conclusion line. Both lines should be at the same height.

On the mandibular cast, two direction points and two conclusion lines are distinguished. The direction points (A' and B') of the mandible are defined as points that determine the change in direction of the mesiodistal curve of the alveolar ridge at the distal end of the retromolar pad (Figure 3).

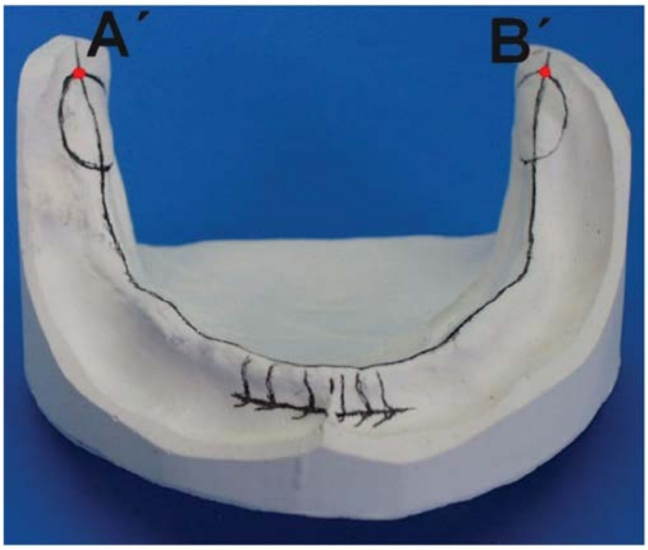

Figure 3.
The direction points and the conclusion line of the mandible [4]

These points are determined by placing an elongated pencil lead parallel to the table and marking the highest point of the alveolar ridge. At the retromolar pad of one side of the jaw, the lead pencil is guided with its tip from mesial to distal on the ridge line. At the end of the retromolar pad there is a change of direction of the course curve. This point is marked with a horizontal line and called the direction point B'. The direction point of the other half of the jaw (A') is determined in the same way (Figure 3).

The conclusion line of the mandible (C') lies on the boundary line between the mobile and attached gingiva. It determines the change of direction in the curve of the vestibule. According to Staub the conclusion line of the mandible should be unchangeable in its anatomical arrangement. To determine it, a pencil lead is inserted into the fold several times on one half of the jaw next to the median axis coming from the alveolar ridge until there is a noticeable change in the direction of the lead. Further lines are traced a few millimeters to the side of the first in the same way. The change in direction is noted again. The same procedure is applied to the other half of the jaw. The changes in direction of the lines are connected to form a horizontal line. This line is called the mandibular conclusion line (C') (Figure 3).

The mathematical calculation of the Staub Penta plane

The Staub Penta plane or Penta area is a cranially assigned occlusal plane in which the position of the teeth and the incisal point are three-dimensionally defined in relation to the scalp or the maxilla. The superior reference plane for the determination of the Penta plane is the maxilla.

After determining the direction points, induction points, and conclusion lines, the Staub Penta plane is determined according to mathematical criteria as follows: The connecting lines of the two direction points A and B with the induction points C and C_1 each result in an equilateral triangle with the line $\overline{AB}$ as base. These distances are the parameters from which the so-called Staub Penta plane is calculated, which is defined as the occlusal plane in the Staub cranial system and is necessary for the reconstruction of the tooth position [4]. Furthermore, the following points and distances are determined, which lead to the determination of the Penta plane in Figure 4:

- Incisal point I
- Canine distance $\overline{FD}$
- Posterior tooth line $\overline{DE}$

A = right point of direction, B = left point of direction, C_1 = rear point of induction, C = front point of induction, I = Incisal point, F = right point of canine position, G = left point of canine position, D = right point of buccal tooth, E = left point of buccal tooth, $\overline{FG}$ = canine position, $\overline{FD}$ = right buccal tooth position, $\overline{GE}$ = left buccal tooth position, $\overline{DE}$ = transversal border line of the buccal tooth position.

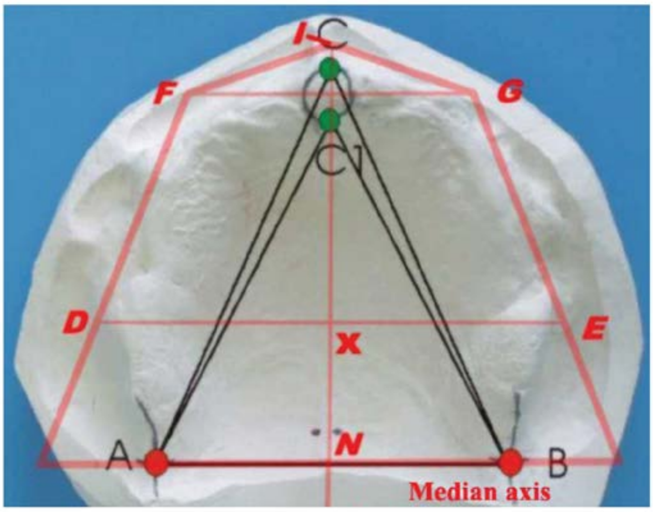

Figure 4.
Computation of the Staub penta level/plane (connecting the points DFIGE)

To reconstruct the tooth position, the two-dimensional position of the incisal point I is determined first. For this purpose, the line $\overline{BC}$ is moved medially until an angle of 90° is formed with line $\overline{AB}$ and placed in the median axis of the maxilla, and the line $\overline{NI}$ is obtained. The starting point N of the line $\overline{NI}$ corresponds to the intersection of the median axis with the line $\overline{AB}$ (Figure 5).

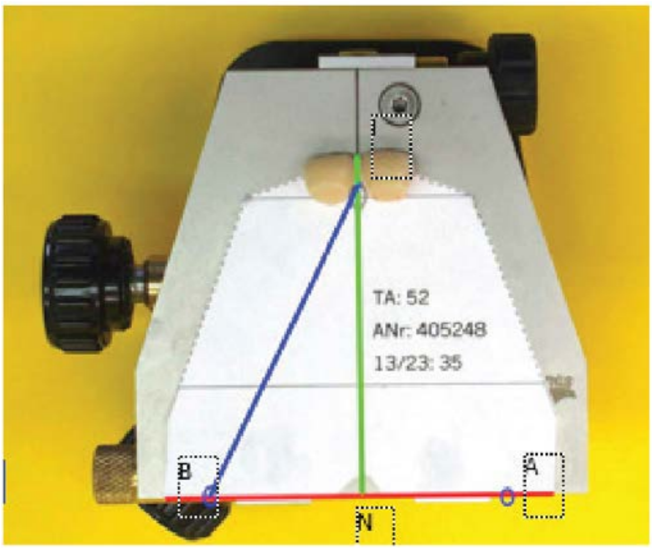

Figure 5.
Incisal point I

This gives the equation: $\overline{NI} = \overline{BC}$.

The canine distance $\overline{FG}$ is calculated as follows (Figure 6): $\overline{FG} = \frac{2\overline{BC}}{3}$

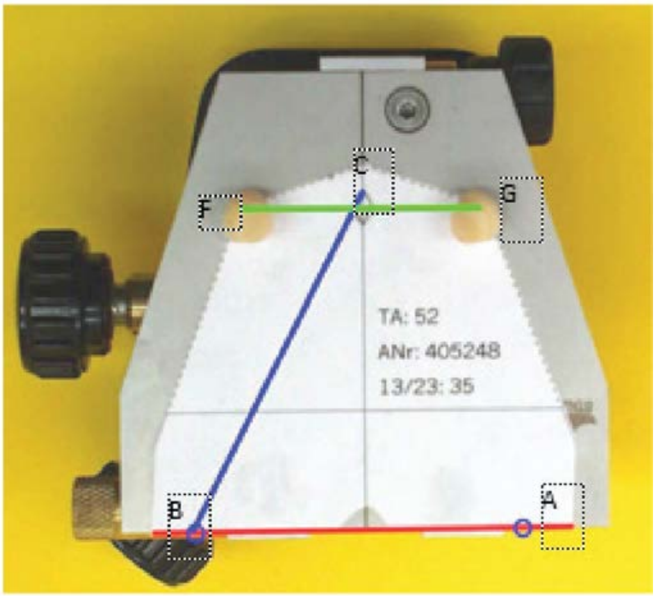

Figure 6.
Canine distance FG (Staub 2011). Green Line =FG,red Line =AB, blue Line = BC

As a prerequisite, $\overline{FG}$ must be parallel to $\overline{AB}$ and $\overline{FG} < \overline{AB}$. The distance $\overline{FG}$ runs exactly through the center of the papilla incisiva P.

At point X, the line $\overline{DE}$ runs perpendicularly through the median axis (Figure 7).

For the calculation of the distance $\overline{PX}$ the equation applies:

$$\overline{PX} = \overline{BC} \times 0.55$$

The transversal boundary line of the posterior tooth path $\overline{DE}$ results from the sum of the distances $\overline{XD}$ and $\overline{XE}$, where the length of these distances is identical (Figure 8).

Since $\overline{XD} = \frac{\overline{BC}}{2} + 2mm$ and $= 2$, it follows:

$\overline{DE} = 2x[\frac{\overline{BC}}{2} + 2mm]$, i.e.

$\overline{DE} = \overline{BC} + 4$ mm

Points D and E correspond to the posterior points of the distances $\overline{FD}$ and $\overline{GE}$. $\overline{FD}$ indicates the future position of the buccal cusps of the replacement teeth for the right and $\overline{GE}$ for the left side of the maxilla (Figure 8). Two mm on each half of the jaw is a constant determined on the basis of empirical observations by Staub, which applies to patients from Central Europe.

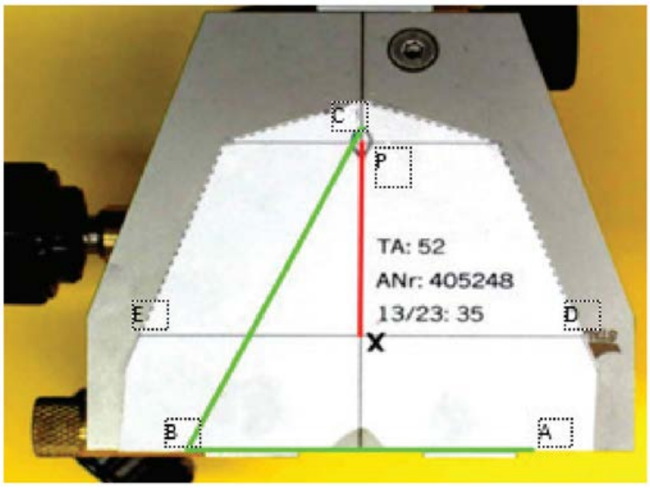

Figure 7.
Computation of the posterior tooth position

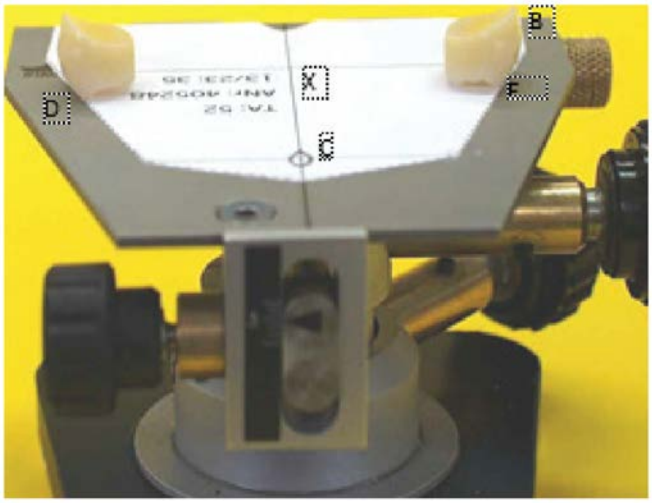

Figure 8.
Transversal borderline of the posterior tooth position

The points D, F, I, G, E together form Staub's Penta plane. A mathematical constant is assigned to this plane in the maxilla and mandible, which determines the incisal point in three dimensions. The constant is defined as the distance from the conclusion line to the incisal point and is 19 mm in the maxilla and 17 mm in the mandible. The values of 19 mm in the maxilla and 17 mm in the mandible were measured by Staub on more than 3,000 dentate models between 1981 and 1987 [4]. The 19 mm constant of the maxilla is correlated to the points N (= center of $\overline{AB}$) and Z (= center of the connecting line between right and left conclusion line) and determines the incisal point I in space with Staub's mathematically determined Penta plane (Figure 9). The distance $\overline{NY}$ = 5 mm corresponds to a mean value determined by Staub on the basis of his empirical observations, which is defined as the distance from the right or left maxillary direction point to the respective opposite mandibular direction point [4]. The 17 mm constant of the mandible is defined as the distance from the center of the mandibular line of conclusion to its incisal point.

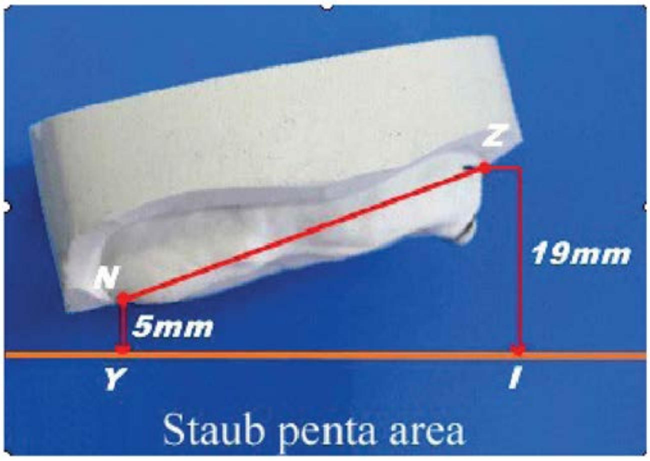

Figure 9.
The location of the penta plane to the upper jaw [4]

CASE REPORT

An edentulous 72 years old male presents with the chief complaint of poorly fitting dentures that do not satisfy function and esthetics (Figure 10).

Figure 10.
Initial removable prostheses in occlusion

According to his report, the denture teeth are quite different from his natural teeth and do not feel natural and in harmony with his face. The patient can be characterized as philosophical according to the House classification [6]. It is decided to apply the Staub principles of teeth set-up in an effort to replace standard guidelines with customized analysis of anatomical landmarks and achieve a more natural prosthesis. No special pretreatment is indicated by the patient history and the clinical examination, and preliminary alginate impressions were followed by final impressions with custom trays and ZnO eugenol paste.

For the Staub Cranial Analysis, the areas behind the maxillary tuberosities in the maxilla, the retromolar pad in the mandible, and the vestibular fold in the maxilla and mandible must be completely preserved and visible on the impression and plaster model. After the working cast has been fabricated, the ridge line has been marked and the cranial reference points have been determined on the cast, the distances $\overline{AB}$, $\overline{BC}$ and $\overline{BC}_1$ are determined and measured on the model with a caliper (in mm). When the three distances are entered into a specially developed software program (Staub®-Cranial Kieferplot, Staub, D-Neu Ulm), a printout of an individual Penta plane is obtained. On these, the patient-specific information on incisal point, canine distance, and posterior teeth line are preserved (Figure 11).

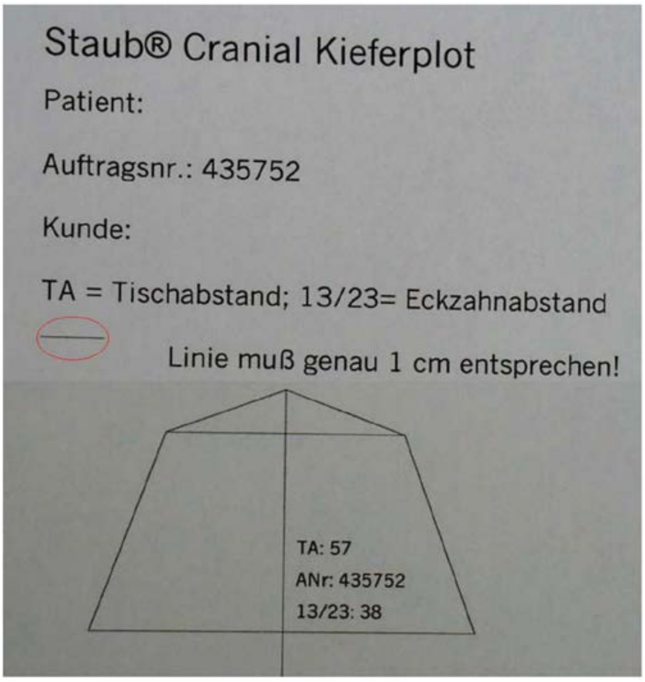

Figure 11.
Printout of a Penta-plane using the example of a patient case

The maxillary cast is aligned with the Penta plane in a special series of appliances. This consists of three units (Figure 12).

- The positioner or the Ortho 1A alignment unit is an independent unit and is necessary for the actual alignment of the maxillary model to the Penta plane.
- Ortho 2A positioner or fixation device is a fixation aid for the maxillary model in order to articulate it into a common articulator system. It is compatible with all common articulator systems.

- Cranial stand Ortho 3A is necessary for merging the Penta plane with the maxillary model, for analysis and fabrication. Ortho 3A is also used in all common articulator systems.

Figure 12.
Ortho 2A, Ortho 1A and Ortho 3A (from left to right)

The maxillary model is aligned three-dimensionally to the Penta plane (occlusal plane) in Ortho 1A. The two direction points are placed on the appliance scale in such a way that the median axis of the maxillary model runs through the zero point of the appliance scale. The maxillary model is additionally stabilized at the conclusion line. Then the model is fixed in the Ortho 1A using a heat gun with an adapter. By loosening the fixing screws of the Ortho 1A, the patient model with the adapter is removed from the unit.

The adapter with the model is placed on the Ortho 2A and is latched onto the fixing part of the mandible in the articulator with the jaw model; thereafter, the maxillary model is articulated.

Subsequently, the dimensionally accurate reproduction of the Penta plane is checked. The line indicated in the printout (Figure 11, line circled in red) must correspond exactly to 1 cm. This is the check that the Staub Cranial System is still calibrated. Using a triangle ruler, draw a transverse line at right angles at the bottom of the printout of the median axis. This line is the direction line. The two side legs are extended to the direction line. The papilla is drawn on the printout. The length of the papilla is the difference from $\overline{BC}$ to $\overline{BC}_1$ (e.g. 57 mm - 52 mm = 5 mm). Median axis and canine line cross in the middle of the papilla. The Penta plane is cut out exactly along the outer boundary lines (Figure 13).

A small notch is removed at each of the direction line and the center line. The printout (Penta-plane) is glued to the Ortho 3A with a glue stick or wax. The median axis must be followed exactly. The direction line corresponds exactly to the end of the Ortho 3A (Figure 14).

Ortho 3A is placed back in the articulator until the front edge of the table forms a vertical line with the incisive papilla. In this position, the distance from the conclusion line to Ortho 3A (constant of 19 mm) is checked (Figure 15).

Figure 13.
Cut out printout of the penta plane. Line outlined in red = papilla incisiva

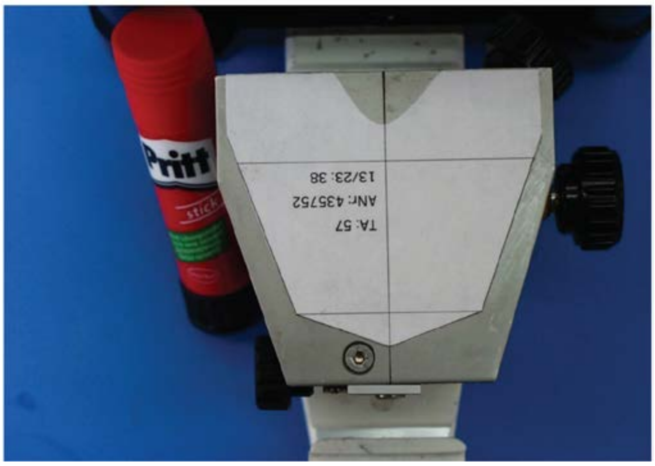

Figure 14.
Glued-in penta plane on the Ortho 3A cranial table

Ortho 3A is then returned to its initial position (zero position). A small amount of plasticine is placed on Ortho 3A at the level of the upper central incisor. The replacement tooth in question is placed with its mesial edge at the tip of the Penta-plane. The articulator is closed. From the frontal view, the lowest point of the papilla incisiva must form a plane with the cervical shoulder in the median axis of the anterior tooth. The front tooth matching in height is selected (Figure 16).

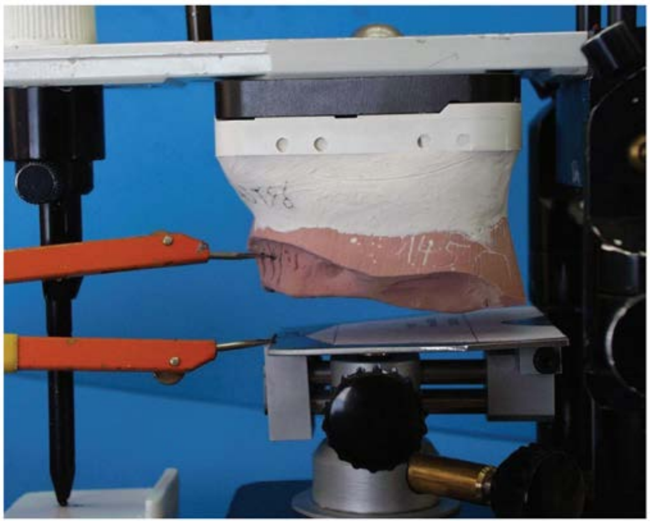

Figure 15.
Control of the 19 mm constant to the conclusion line

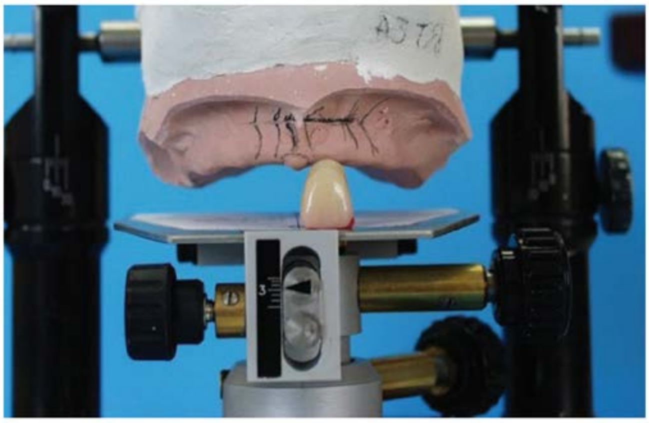

Figure 16.
Checking the space conditions

Using plasticine, the canine tooth is placed on the corner of the Penta level from the same set of teeth. The lateral incisor is inserted in an arch between the two teeth. If the gap is too small, the selected teeth are too wide; if the gap is too wide, the teeth are too narrow. The selection procedure is repeated in the same way until a suitable tooth shape is found. If this is the case, the central incisor is again set at the tip of the Penta plane with plasticine. Its labial surface is placed perpendicular to the Ortho 3A. The canine and lateral incisor are again placed in plasticine. The lateral incisor does not need to touch Ortho 3A. The other dental arch segment is completed in the same way (Figure 17) and the space conditions are checked in the closed articulator.

The posterior set matching the anterior teeth is selected according to the instructions of the manufacturer of the arch teeth. A pencil lead is used to draw a line over the buccal cusp tips. This line touches the boundary line of the Penta area when set up. A strip of plasticine is pressed firmly onto Ortho 3A. The boundary line is kept free. The first premolar is positioned vertically on the surface. The buccal cusp tip runs parallel to the lateral surface of the Penta plane. The second premolar is also set with the buccal and palatal cusp tip perpendicular to the surface. The mesio-palatal cusp of the first molar is putted so that the mesio-buccal cusp tip is 1 mm outside the Penta border and – in contrast to the distal cusps – is only slightly raised from the Penta plane. The space conditions in the articulator are checked and the teeth are ground basally if necessary. The tooth set-up of one half of the jaw is completed (Figure 18).

Figure 17.
Set-up of the upper front teeth

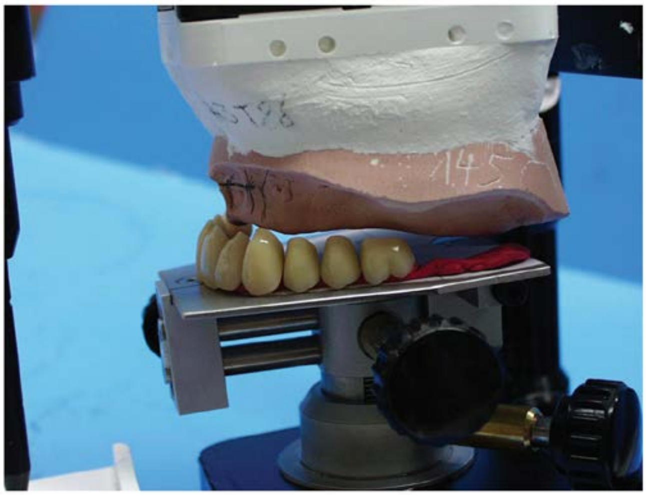

Figure 18.
Set-up of the upper posterior teeth and check of the space conditions

After the tooth set-up of the other side has been carried out with the same criteria, a pointed caliper is used to pierce at the crossing point of the Penta plane. The length to the buccal neck of the tooth is made at the center of the first molar and compared with the opposite first molar at the same tooth point. If the distances are identical, the tooth positions are also identical (Figure 19).

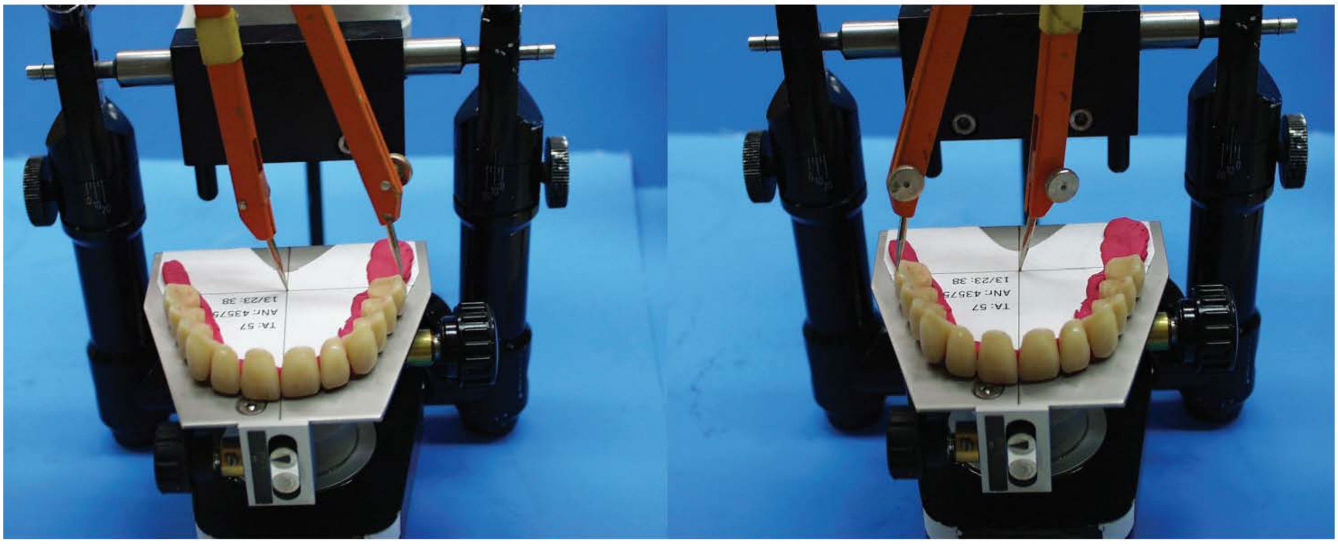

Figure 19.
Checking the tooth positions of the upper first molars

The tooth positions are only readjusted if necessary. The position of tooth 23 with the position of tooth 13 are also checked.

Subsequently, the teeth are fixed to the cranial table with a heat gun or adhesive wax. The palatal part of the tooth is covered with plasticine until only 1 mm of the tooth neck is visible.

The maxillary model and the set-up teeth are then isolated against acrylic and a base plate made of acrylic is stamped onto the teeth. The base plate is finished with a handpiece. The teeth are fixed to the base plate with wax. A plastic base plate is fabricated on the mandibular model and completed with wax to form a registration rim.

In complete denture prosthetics, the Staub model analysis already includes a maxillary set-up in acrylic with twelve teeth and a mandibular registration rim with wax after the first situation impression by the dentist. These also serve as bite registration and functional trays for the final impressions. The maxillary set-up is also tried on at this time; any changes can be made by the dentist. After the functional impression on the patient, the master models are made and the maxillary model is articulated with a facebow if necessary. The second molar in the maxilla is set up with a harmonic inclination to the curve of Spee. The mandible is brought into relation to the maxilla with the help of the registration template and also articulated. The conclusion line and direction points are drawn on the mandibular model. In the anterior region, plasticine is pressed firmly onto and behind the alveolar ridge at an even distance from the maxillary anterior teeth (Figure 20).

Figure 20.
Initial situation for the mandibular set-up

The set-up of the lower teeth begins with the central incisor in plasticine (Figure 21). The articulator is closed and the tooth position corrected if necessary. After opening the articulator, the tooth is checked for the height of 17 mm from the mandibular conclusion line.

If this is the case, the lateral incisors and the canines are added in sequence on the left and right side (Figure 22).

In the posterior region, it is recommended to start the set-up with the first molars, because these teeth have the largest occlusion area. Subsequently, the second premolar, the first premolar, and the second molar are completed (Figure 23). The same procedure is followed on the opposite side.

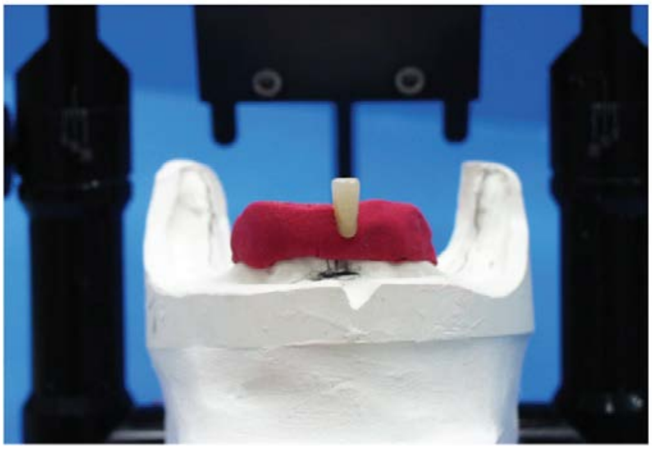

Figure 21.
Set-up of the lower central incisor

Figure 22.
Set-up of the lower anterior teeth

The tooth arches are now completely set up. The tooth row is bonded against the maxillary tooth arch, the articulator is opened and the basal plasticine is removed. The row of teeth attached to the maxilla is covered lingually with plasticine to such an extent that only 1 mm of the tooth neck remains visible (Figure 24).

The plaster model and the teeth are isolated against acrylic and stamped in an acrylic material (Figure 25). The teeth are fixed in the "alveoli" with wax. The set-up can now be given to the clinic as a complete try-in.

Figure 23.
Set-up mandibular posterior teeth

Figure 24.
The fixed mandibular set-up

Figure 25.
The stamped lower jaw base

After try-in and necessary modifications, fabrication was performed with conventional thermal polymerization of poly methyl methacrylate (PMMA) and prostheses of improved function and esthetics were delivered to the patient (Figure 26).

DISCUSSION

In the prosthetic literature, there are many papers describing methodologies for the establishment of the occlusal plane in its original position before loss of the natural teeth [7][8][9][10]. Several cephalometric points of reference were described, which entail different definitions of the reconstructed occlusal plane. According to the most common definition, the occlusal plane is a mean level, which is formed by the proximal point of contact of the lower central incisive and the distal-buccal cusp tip of the second lower molar [11]. In the Glossary of Prosthodontic terms [12] the occlusal plane is defined as the average plane established by the incisal and occlusal surfaces of the teeth. It is not a surface in the actual sense, but represents the mean curvature of the surfaces.

Figure 26.
Final removable prostheses in occlusion

According to many authors, the occlusal plane runs parallel to Camper plane (Ala Tragus line) [8][13][14][15][16][17]. The Camper plane is the level at the human face, which is defined by three points: spina nasalis anterior and superior margin of the tragus, right and left. It runs approximately parallel to the occlusal plane. Therefore, it can be used in the fabrication of complete dentures to reconstruct the occlusion [11].

Hartono [18], Karkazis *et al*. [14], Koller *et al*. [19] and Sinobad [20] agreed that the definition of the Camper plane can be described as the level by the spina nasalis anterior and the lower margin of the meatus acusticus externus, since this position is nearly parallel with the natural occlusal plane.

The Staub™ Cranial system is not the first system in the history of dentistry with the promise to reconstruct the individual position of the occlusal plane with dentures. For example, Lundenhausen [21] presented the complex system for the individual position of the jaw in relation to the skull. Unfortunately, no scientific study is known for this system.

Monteith [8] reported that if the porion nasion spina nasalis anterior angle (PoNANS), measured in a lateral cephalometric X-ray, is inserted into a mathematical equation, another angle results, which indicates the inclination of the occlusal plane in relation to Frankfurt horizontal. The equation reads: $Y = 83.4307 - (0.9907 \times X)$; the value of the PoNANS angle substitutes X in the equation; the equation is then dissolved after Y. The result indicates the inclination of the occlusal plane in relation to Frankfurt horizontal. Monteith [8] developed a fixing table for the Hanau articulator (Model XP-117, Teledyne Hanau, Buffalo, N.Y.), which transfers these angles to the articulator.

Karkazis and Polyzois [22] applied Monteith`s equation to two groups: dentate subjects (10 men, 12 women) with good occlusal conditions and edentulous patients with complete dentures (22 men, 22 women). The results reveived could not confirm Monteith`s equation.

The Accu Liner™ system of Carlson [5] uses the HIP-plane, which is formed by the Papilla incisiva and the two Hamuli pterygoid, for articulating upper jaw casts. The HIP-plane lies parallel to the horizontal plane and Camper plane (Figure 27).

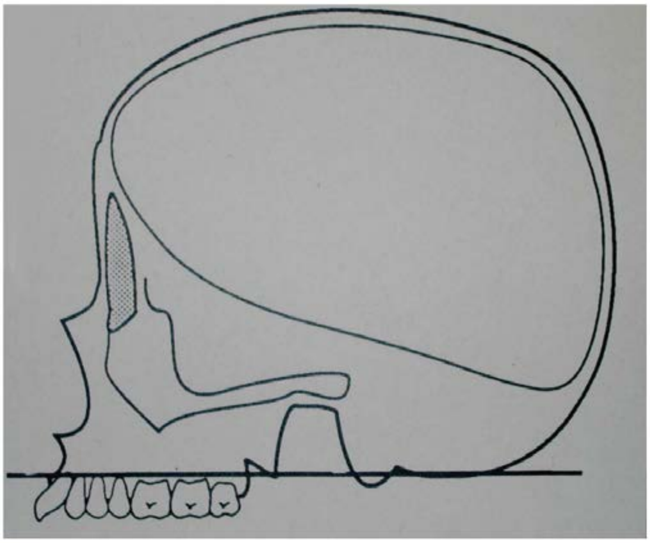

Figure 27.
HIP-Plane [5]

Carlson [5] used the definition for the Camper plane as the plane running from the spina nasalis anterior and the centre of the Porus acusticus externus. Carlson’s system could be regarded as the direct competitor of the Staub™ Cranial system, since similar results and uses of the manufacturer are promised.

Karkazis and Polyzois [22] examined the parallelism of the HIP plane for the occlusal plane and found that between the two levels an average angle of 4.31° is formed. The basic adjustment of the Accu Liner™ system, due to the absolute parallelism with the horizontal plane, is not suitable for normal space conditions when setting up replacement teeth. If a direct comparison between the HIP-plane of the Accu Liner™ system and the Penta plane of the Staub™ Cranial system would fail to favour the second, must be verified by a study.

The Staub Cranial System cannot detect or reconstruct previous spaces or crowding in the dental arch. Instead, it determines the appropriate tooth size for a given jaw size. In this way, deviations from the former actual condition may occur during reproduction.

In cancer patients after resection on the maxilla in the area of the needed anatomical reference points or in patients who have suffered a fracture on the maxilla, the necessary anatomical information may be missing [23]. The applicability of the Staub system is naturally limited in these cases. However, the experienced user could possibly still use it in such cases due to the parallelism of the conclusion line to the line AB. The prerequisite for this would be that one side of the maxilla is preserved after resection. Nonetheless, the applicability of the system in such cases remains to be proven by future studies.

CONCLUSIONS

Using the Staub Cranial Analysis and Fabrication System, points are defined first, then distances and planes. This is similar to the procedure for evaluating cephalometric images in orthodontics.

The documented procedure demonstrates the potential for practicable clinical implementation of the Staub Cranial system. It is easy to integrate the system into conventional therapeutic in orthodontics, prosthodontics, and implantology, for instance. It also could be integrated in digital workflows for complete denture fabrication. Nonetheless, further investigations are needed to evelop these and other areas of application of the system and to demonstrate its advantages over conventional therapeutic procedure.

Conflict of Interests

The authors report no relevant conflicts of interest.

Financial Disclosure Statement

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Human Rights Statement

All procedures followed were in accordance with the Helsinki Declaration of 1964 and later versions. Informed consent was obtained from the patients.

Animal Rights Statement

Not applicable.

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