Article

Choice of Screws for Fixation of Mandibular Condyle Fractures Guided by Anthropometric Data

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Abstract: Open reduction and internal fixation (ORIF) is becoming increasingly common in treatment of the condylar process, including mandible head fractures. This approach significantly improves the results in terms of anatomical reduction of bone fragments, and shortens the treatment time, allowing for early functional recovery. The success of ORIF is largely determined by the stability of the osteosynthesis. The stabilization effect depends on the screw type and length of the plate used, in addition to the diameter and length of the screws used. The aim of this study was to determine the largest possible screw length that can be used in ORIF of the mandibular condyle considering the variable bone thickness. A total of 500 condyles were examined using computer tomography (CT)-based 3D models in Caucasians. For all models, three measurements were made in the frontal projection in places typical for the stabilization of osteosynthesis plates in the fractures of the condylar process: the base, the top, and the sigmoid notch. In addition, one measurement of the mandible head was made in the place of the greatest width. The results showed that 8 mm screws should be used in the region of the condylar base as the longest anatomically justified screw, whereas in the area of a sigmoid notch only 1.5–2 mm screws should be used. Measurements in the area of the neck top revealed statistically significant differences in the measurements between the sex of patients, with average differences below 1 mm ($p < 0.05$). In this area, the maximal length of the screw was found to be 10 mm. In mandibular head fractures, the use of long screws is extremely important due to the desired effect of fragment compression. Statistically significant differences were found in the measurement results between women and men. The maximal screw length for bicortical fixation was found to be 22 mm in men and 20 mm in women. In post-traumatic patients, the ability to obtain a clear measurement is often limited by a deformed anatomy. Taking into account the fact that the fracture stability is influenced by both the plate length and the length of the fixation screws, an assessment of the standard measurement values in a cohort group will improve the quality of the surgical fixations of the fractures.

Keywords: mandible condyle; fan-beam computed tomography; cone-beam computed tomography; segmentation; surgical treatment; compression screw; plates

1. Introduction

Open reduction and internal fixation (ORIF) is an increasingly popular method used in the treatment of the condylar process [1] and mandible head fractures [2]. This approach significantly shortens the healing process and allows for early restoration of function (in the first day after surgery) [3]. Currently, the most commonly used surgical approaches (low submandibular, retromandibular transparotid, preauricular, submandibular, and deep retroparotid approaches) carry a risk of complications, the most serious of which is the formation of an extraoral salivary fistula (incidence 2.3%) [4] and facial nerve functional impairment (incidence, depending on the development, 8.6–55%) [5]. It is worth emphasizing, however, that permanent facial nerve palsy is rare (0.3–2.2%, depending on access) and in most cases it resolves after a few months [6].

The success of ORIF is largely determined by the stability of the fixation [1,7]. This depends on the type and length of the plate used, in addition to the width and length of the osteosynthetic screws [8]. Among the factors influencing the stability of the fixation, the type of fixing material has also been mentioned [9,10].

The aim of this study was to determine the largest possible screw length that can be used in ORIF of the mandibular condyle considering variable bone thickness.

2. Materials and Methods

The approval of the bioethics committee at the Medical University of Lodz, numbers RNN/125/15/KE and RNN/738/12/KB, was obtained for the study. All computed tomography images were acquired after anonymization [11] from the Maxillofacial Surgery Clinic Database: 66 cone-beam computed tomography (CBCT) images, Carestream CS 9300 3D (Carestream Dental LLC, Atlanta, GA, USA), and 184 fan-beam computed tomography (FBCT) volumetric scanner (Aquilion ONE, Toshiba, Otawara, Japan) images. CT scans of healthy Caucasian patients aged 8–88 (average 44.56 ± 18.12) constituted the inclusion criterion for the study.

Study images of patients suffering from degenerative changes in the TMJ region (e.g., ankylosis) and modeling changes of the mandible (tumor growth, dysplasia) were excluded.

CT scans of post-traumatic patients in the region of the mandible, after ORIF and after resection of mandible, were also excluded from the study. The exclusion criteria also included low quality of the tomography and numerous artifacts in the images.

Using histogram analysis, bone segmentation was performed using global thresholding defined for the CBCT and FBCT by the individual histogram analysis according to the Baillard and Barillot protocol [12]. DICOM axial images were transformed into three-dimensional bone models. Each model contained two condylar process results in the 500 obtained CT-based 3D models. The subsequently obtained models were subjected to measurements. Segmentation, model preparation, and measurements were performed using Mimics 17.0 software (Materialise, Leuven, Belgium).

For all models, the auxiliary "base line" was determined based on the algorithm described by Neff [13] (Figure 1). All of the above measurements were applied to the models perpendicularly to the base line.

Auxiliary lines: neck_basal (between the lowest point in the semilunar notch and the most backward point at its height) and neck_top (between the most forward and most backward point at the level of the condylar head reference line described by Neff) [13];

- Width_neck_basal—width between the most mesial and distal point at the level of neck_basal;
- Width_neck_top—width between the most mesial and distal point at the level of neck_top;
- Width_head—the widest measurement of the head of the mandible;
- Thickness_sigmoid_notch—width measured 1 mm below the sigmoid notch.

Statistical analysis was performed in Statgraphics Centurion 18 (Statgraphics Technologies Inc., The Plains, VA, USA).
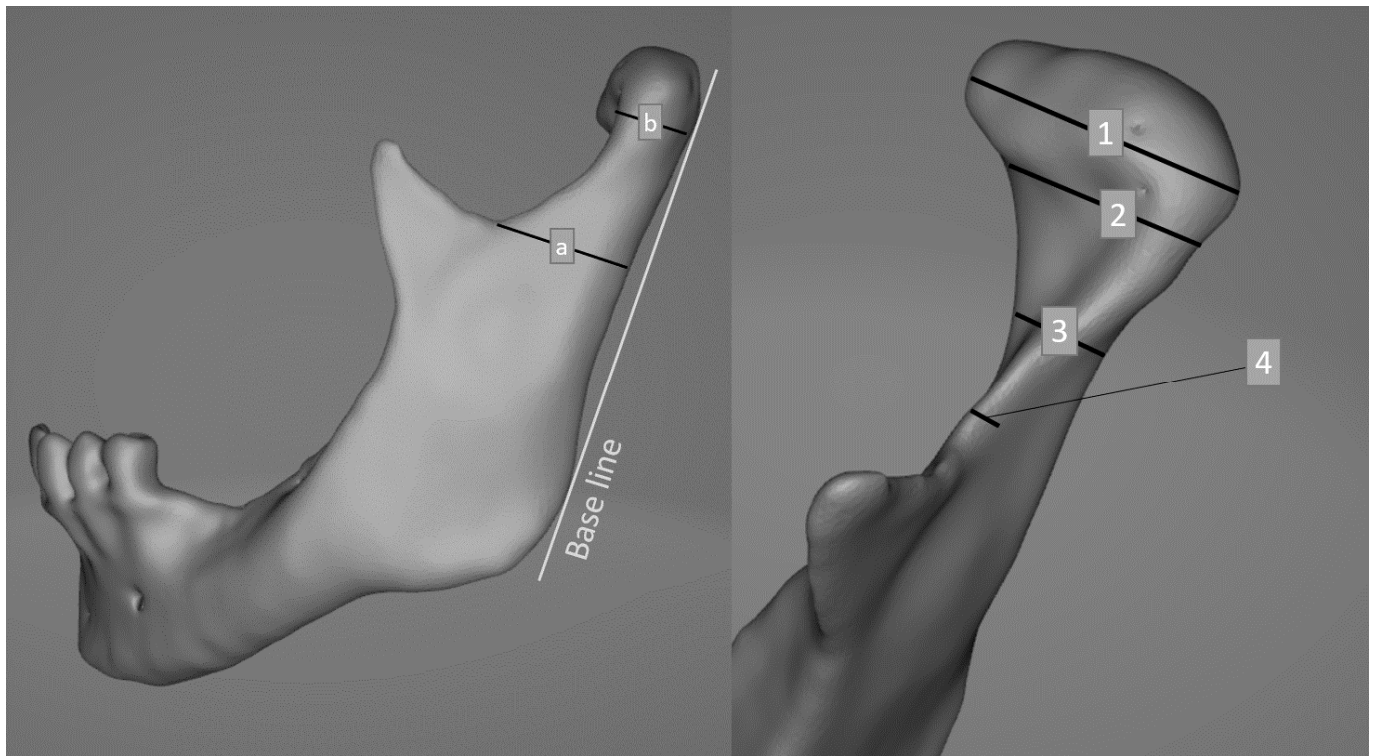
Figure 1. Anatomical measurements, auxiliary lines, and base line: neck_basal (a), neck_top (b), Width_head (1), Width_neck_top (2), Width_neck_basal (3), and Thickness_sigmoid_notch (4).

3. Results

The mean Width_neck_basal was 10 ± 3.01 mm, the mean Width_head was 20.45 ± 2.49 mm, the mean Thickness_sigmoid_notch was 2.04 ± 0.77 mm, and the mean Width_neck_top was 10.04 ± 0.8 mm. The distribution was platykurtic for Width_neck_basal, and leptokurtic for Thickness_sigmoid_notch and Width_head. For the width_neck_basal and Thickness_sigmoid_notch measurements, there was a strong right skewness, whereas for the Width_head measurement, there was a strong left skewness.

Analysis of age-correlated measurements using the simple regression analysis test showed a statistically significant relationship ($p < 0.05$) for Width_neck_basal, Thickness_sigmoid_notch, and Width_head (Figure 2). There was no age relationship for the Width_neck_top measurement.

Analysis of Width_neck_basal vs. sex of the patients using the Kruskal–Wallis test and analysis of Thickness_sigmoid_notch vs. sex of the patients using the ANOVA test showed that the above measurements were not sex-dependent ($p > 0.05$) (Figure 3).

Plot of Fitted Model

Width_neck_basal = sqrt(9.74743 + 27.7643*ln(Age))

Plot of Fitted Model

Width_head = sqrt(309.884 + 31.728*ln(Age))

Plot of Fitted Model
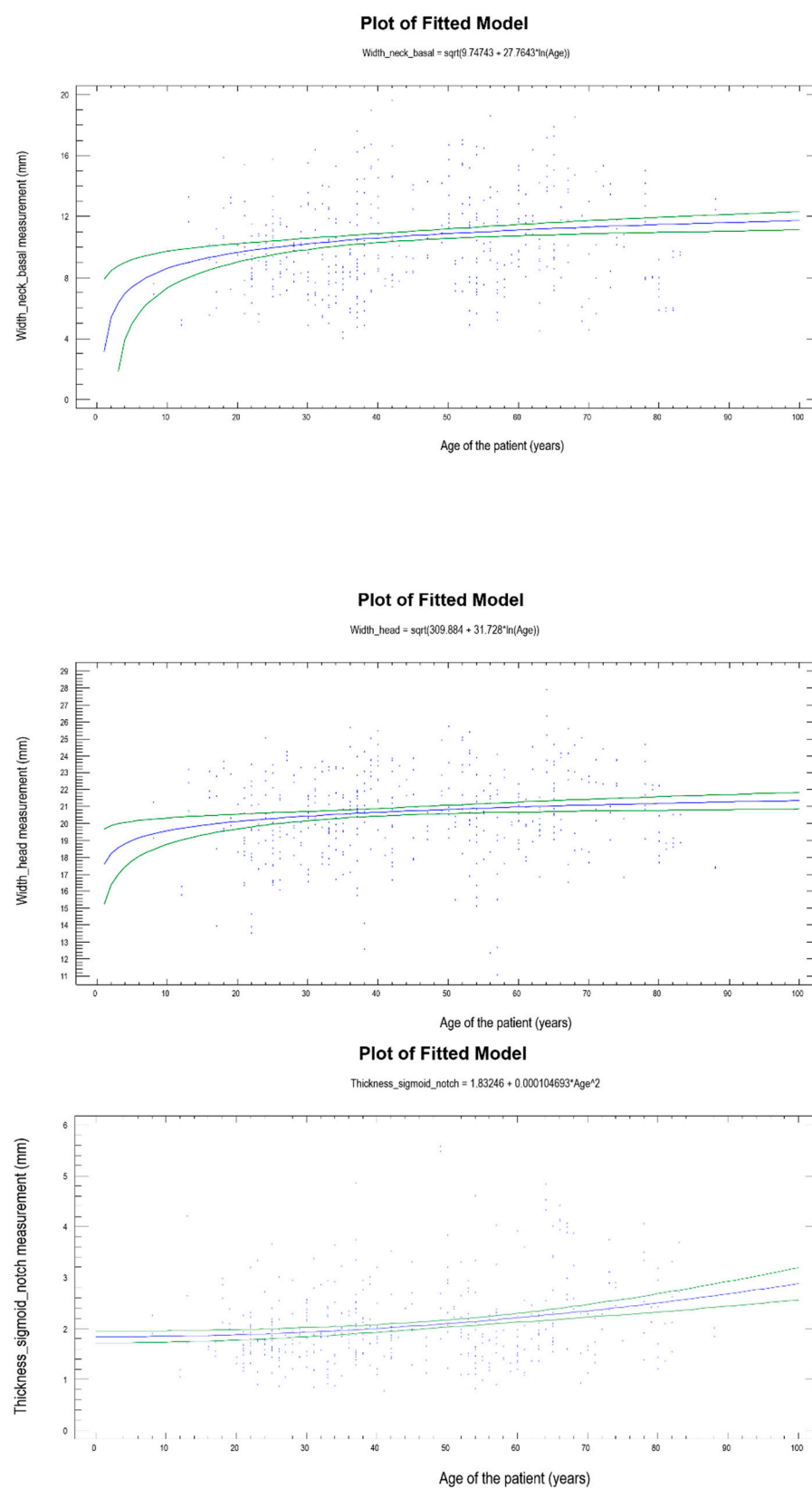
Thickness_sigmoid_notch = 1.83246 + 0.000104693*Age^2

Figure 2. Results of the analysis of measurements of Width_neck_basal, Thickness_sigmoid_notch, and Width_head vs. age of the patients ($p < 0.05$).

Box-and-Whisker Plot
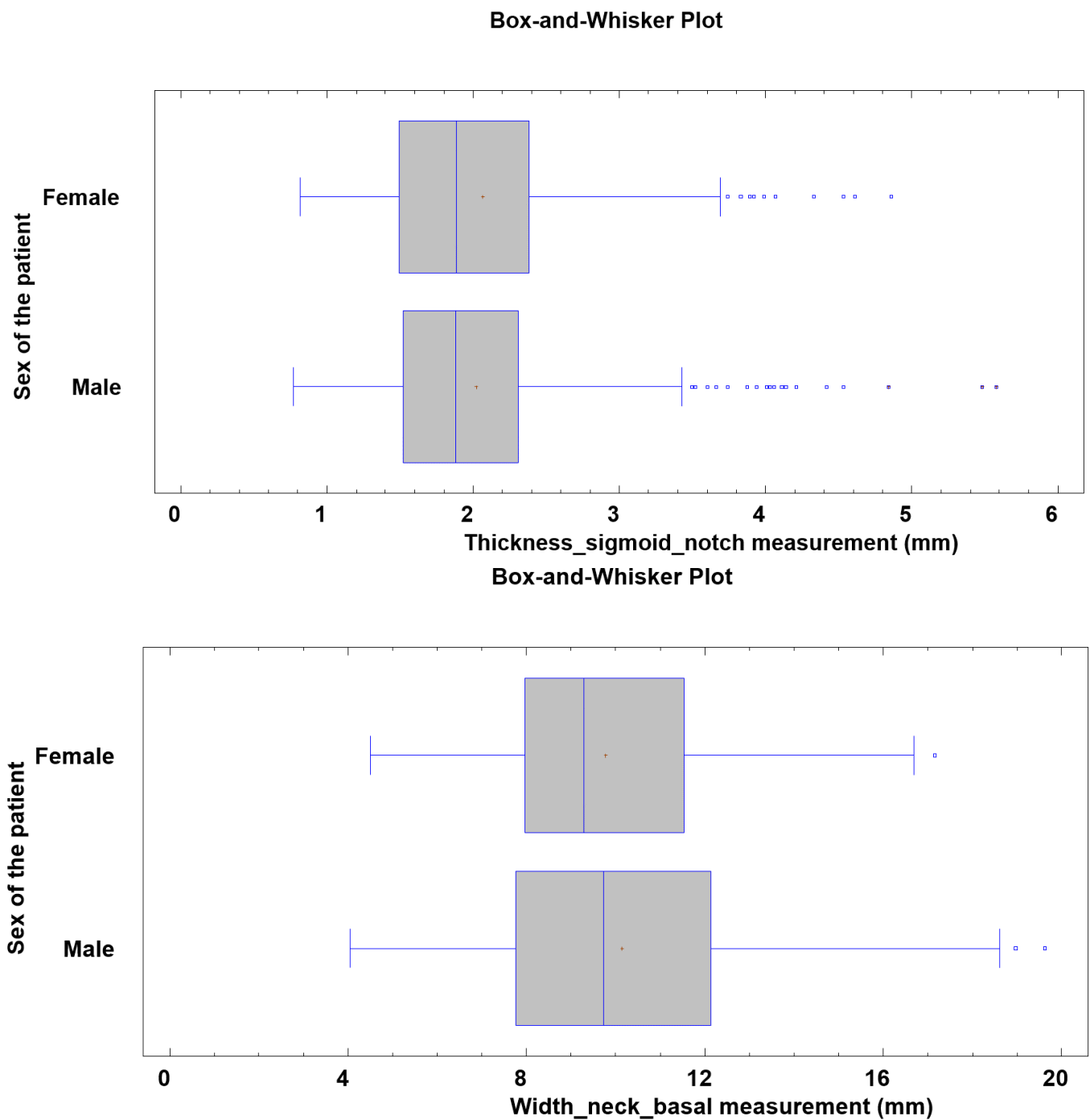

Box-and-Whisker Plot

Figure 3. Results of the analysis of measurements Width_neck_basal and Thickness_sigmoid_notch vs. sex of the patients ($p > 0.05$).

By comparison, the ANOVA test showed statistically significant differences in the Width_head measurement results, depending on the sex of the examined patients ($p < 0.05$). In males, Width_head was 21.1 ± 2.16 mm, whereas in females it was 19.31 ± 2.62 mm. The distributions in both cases revealed a left-hand skewness. Statistically significant differences ($p < 0.05$) were also obtained when analyzed by Width_neck_top using the Kruskal–Wallis test. In men, the Width_neck_top was 10.06 ± 0.84 mm, and in women, 9.99 ± 0.71 mm. In both cases, the distributions also revealed a left-hand skewness (Figure 4) (Table 1).
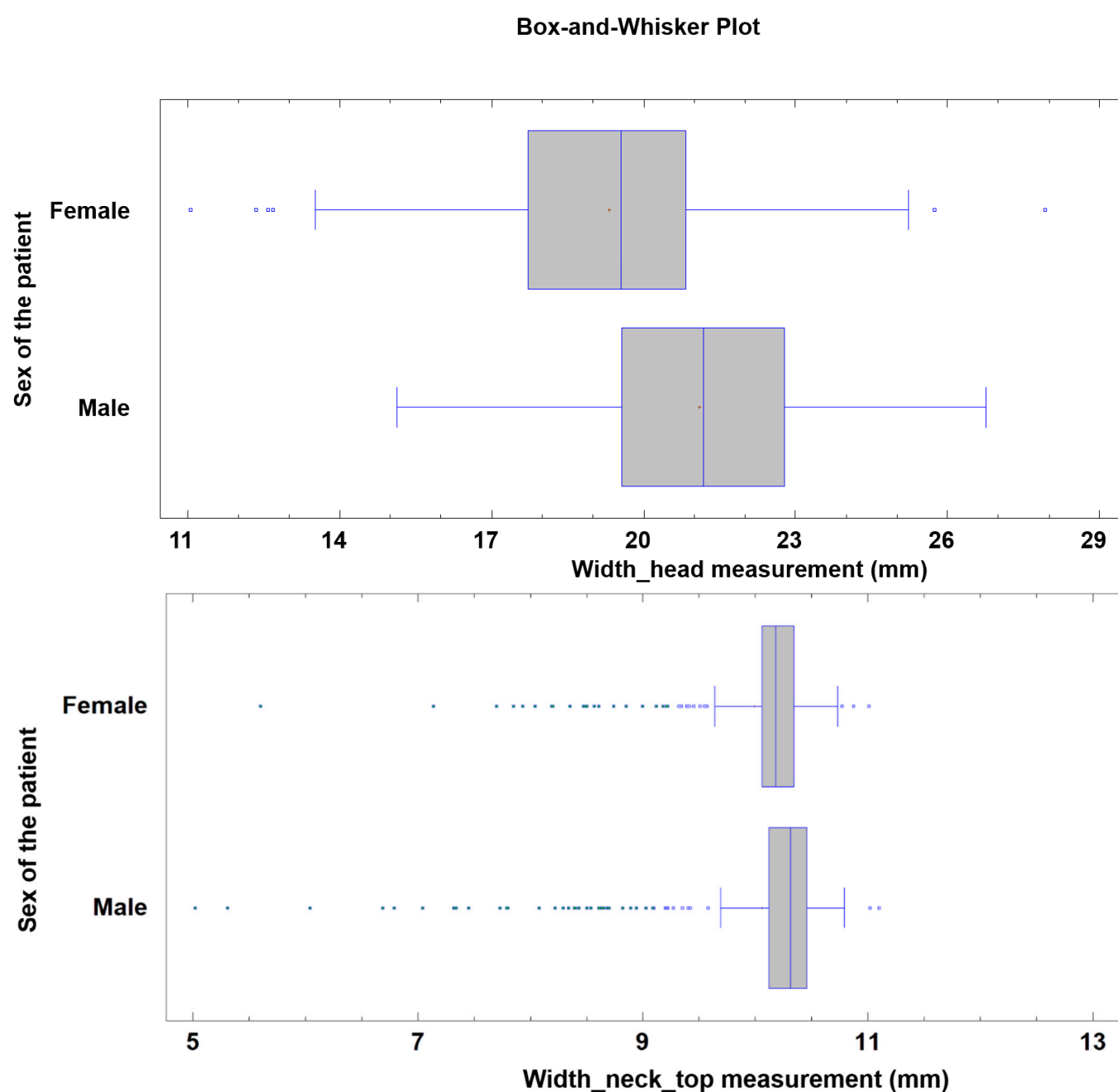
Box-and-Whisker Plot

Figure 4. Results of the analysis of measurements Width_head and Width_neck_top vs. sex of the patient ($p < 0.05$).

Table 1. Anatomical measurements correlated with the age and sex of the patients.

Measurement Names	Mean ± SD	Female Mean ± SD	Male Mean ± SD	Sex of the Patient vs. Measurement Statistical Significance	Age vs. Measurement Statistical Significance
Width_neck_basal	10 ± 3.01	9.78 ± 2.73	10.14 ± 3.15	$p > 0.05$	$p < 0.05$
Width_neck_top	10.04 ± 0.8	10 ± 0.71	10.06 ± 0.84	$p < 0.05$	$p > 0.05$
Width_head	20.45 ± 2.49	19.31 ± 2.62	21.1 ± 2.16	$p < 0.05$	$p < 0.05$
Thickness_sigmoid_notch	2.04 ± 0.77	2.06 ± 0.78	2.02 ± 0.76	$p > 0.05$	$p < 0.05$

4. Discussion

4.1. Issues Related to the Surgical Treatment of the Condylar Process and Mandibular Head Fractures

The treatment of both the condylar process and mandibular head fractures has been controversial for some time. Among the methods used, two basic treatment techniques can be distinguished: ORIF or conservative treatments of closed reduction, intermaxillary fixation, traction, physiotherapy, or even no treatment. Each of these types of treatment has its advantages and disadvantages: conservative treatment can lead to an open bite, malocclusion, chronic pain, or ankylosis, resulting in complete blockage of the joint [14,15] if a dislocated fracture occurs.

Currently, the standard ORIF of the condylar process is titanium alloys when resorbable polymer anastomoses have failed in terms of strength [16]. Metallic resorbable osteosynthesis is under consideration [10]. This may be an important alternative to nonresorbable titanium fixation in the future [17].

Rigid fixation is considered the treatment of choice by many authors in fractures of the condylar process [18] and the mandibular head [2], ensuring the anatomical stability of the osteosynthesis [19], which is necessary to obtain the correct occlusion after the procedure [20], in addition to recovery and efficient mastication. Complications associated with abnormal union formation after fracture fixation are associated with infection, an atrophic mandible, inappropriate reduction, multiple fractures, repeated trauma, patient compliance, and, in particular, poor stability [21]. Fracture infections promote the activity of fibroblasts in relation to the activity of osteoblasts. This results in fibrous adhesions, which results in non-union [22] and mobility of pathological bone fragments.

Ribeiro-Junior et al. compared the incidence of postoperative complications related to the stability of occlusion, and showed that edentulous patients or patients with unstable occlusion have a greater chance of developing complications after osteosynthesis performed with 2.0 and 2.4 mm fixation systems [23]. The influence of occlusion on the stability of the fixation osteosynthesis treatment was also demonstrated by Shetty et al. and Nishimoto et al., who assessed postoperative stability as a statistically significant component of the Mandible Injury Severity Score (MISS). They also included parameters such as fracture type, location, soft tissue involvement, infection, and displacement of the fracture. A higher MISS determines both the severity of the fracture in terms of fixation and the probability of complications [24,25].

Another factor that modifies stability is the shape of the plates. Small plates do not perform well mechanically [26]. However, among the many plate shapes available, it is possible to choose the most durable plate as a base for the condyle fracture [27] (which is a relatively easy fracture to treat) and for ORIF of the condylar neck [20,28]. Due to limited space, ensuring proper fixation stability is a challenge, especially in the condylar neck top region [28]. The use of an appropriate fixation material in the form of two osteosynthetic plates for wide and low condylar processes (less than 10 mm) [29] or a dedicated plate for long and slender processes is crucial to ensure a long-lasting treatment effect [30]. The use of the correct screws is crucial in this case.

When considering the issue of the length of screws fixing the plates, it should be noted that the longer the screws used, the stronger they anchor in the bone and stabilize the osteosynthesis [31–33]. The longer the screw, the more stable the fixation, even for plateless osteosynthesis [34,35]. Thus, it is advisable to determine the thickest osteosynthesis-suitable bone regions in the mandible. Furthermore, higher screw diameters can be used in thicker bone sites [36], thus benefiting stabilization.

4.2. Clinical Relevance of the Study

In post-traumatic patients, the ability to obtain unambiguous measurements is often limited by a deformed anatomy. Taking into account that the fracture stability is influenced by both the plate length and the length of the fixation screws [8], an assessment of the

standard measurement values in a large study group will improve the quality of the surgical fixations of fractures by avoiding the use of screws that are too short.

Measurements were performed in places typical for the stabilization of osteosynthesis plates in the fractures of the condylar processes, i.e., the base, the top, and the sigmoid notch [34] (Figure 5).
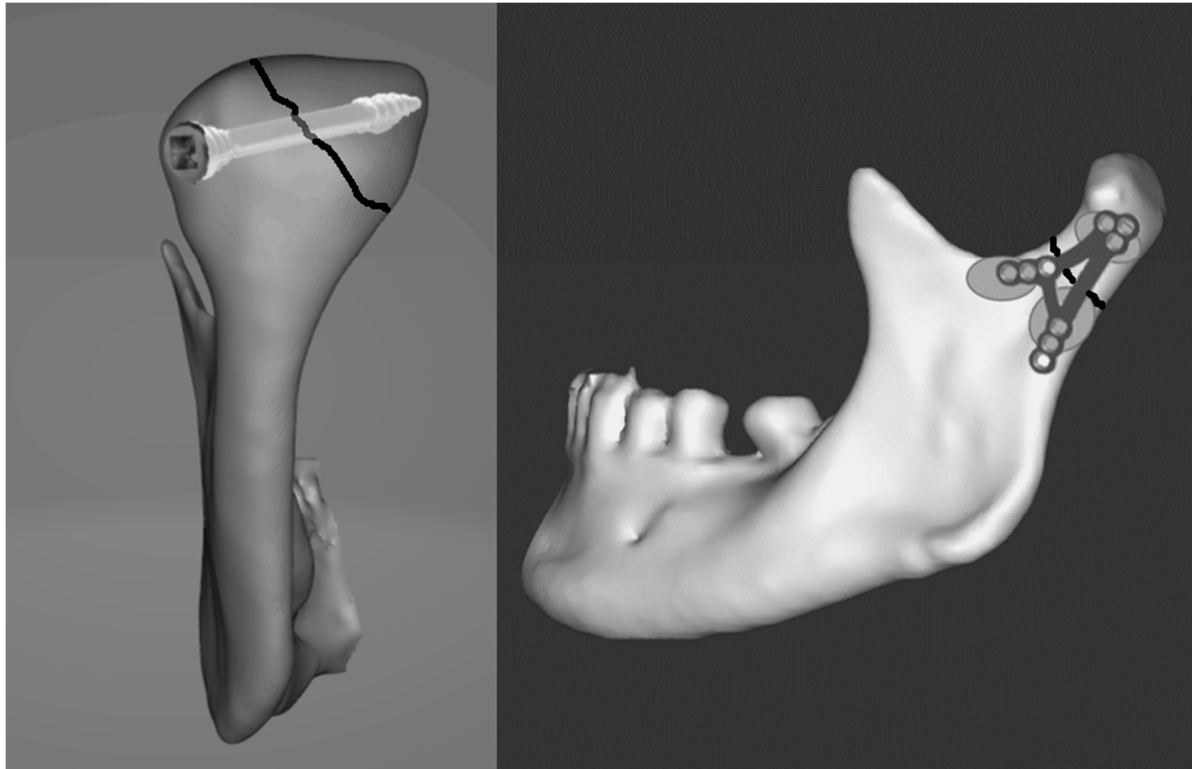

Figure 5. Typical fixation of the mandibular head with the exemplary headless compression screw (**left**) and the location of the ACP plate for condylar fracture fixation (**right**).

Thus, in the area at the base of the condylar process, 8 mm screws should be chosen (due to the skewness of the distribution). In the area of the sigmoid notch, 1.5–2 mm screws should be chosen. Both of the above measurements were not gender dependent ($p > 0.05$).

Measurements in the region of the condylar neck top revealed statistically significant differences in the measurements between the sex of the patients, but the average difference was below 1 mm ($p < 0.05$). In this area, an appropriate choice would be 10 mm screws.

In mandibular head fractures, the use of long screws is extremely important due to their mechanism of action (strong compression and bicortical anchoring) [37]. Luo et al. obtained statistically better results in the treatment of mandibular head fractures using long bicortical screws compared to osteosynthesis with the use of mini-plates and monocortical screws as well as compared to the removal of the fractured part of the mandibular head [38].

The use of an appropriate screw to ensure proper stability is important because reoperation in the mandibular head area is associated with a higher risk of complications related to facial nerve palsy [10].

Statistically significant differences were found in the measurement results between women and men. Taking into account the distribution of the features, it can be concluded that the standard length of the bicortical screws that should be used in men is 22 mm and 20 mm in women.

It should also be mentioned that there is a statistically significant correlation between some measurements (Width_neck_basal, Thickness_sigmoid_notch, Width_head) and the age of the examined patients. Depending on the age of the patients, values of the measurements Width_neck_basal and Width_head increase as described by the fol-

lowing two formulas, respectively: $\text{Width\_neck\_basal} = \sqrt{9.74743 + 27.7643 \times \ln(\text{Age})}$ and $\text{Width\_head} = \sqrt{309.884 + 31.728 \times \ln(\text{Age})}$. It should therefore be assumed that the values of the measurements Width_neck_basal and Width_head are lower in the younger patient group, increasing with age in a logarithmic manner. A statistically significant relationship described by the formula $\text{Thickness\_sigmoid\_notch} = 1.83246 + 0.000104693 \times (\text{Age})^2$ was observed between the Thickness_sigmoid_notch measurement value and the age of the examined patients. Measurement values were observed to increase with age in an exponential manner.

5. Conclusions

In post-traumatic patients, the ability to obtain clear measurements is often limited by a deformed anatomy. An assessment of the standard measurement values in a large study group will improve the quality of the surgical fixations of fractures because the fracture stability is influenced not only by the plate mechanical feature but also by the length of the fixation screws. In fractures fixed only with screws, as is the case in the mandibular head, the selection of the correct screw length is crucial.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Ethics Committee of Medical University of Lodz (protocol code RNN/125/15/KE and RNN/738/12/KB approval date: 19 May 2015; 20 November 2012; respectively).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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