



Pomorski Uniwersytet Medyczny
w Szczecinie

PAN - Instytut Immunologii
Wpl. dnia 08.01.2026.....
L.dz.11.....

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Szczecin, dn.6.01.2026

REVIEW

of the doctoral dissertation by Joanna Heuchert, MA entitled “Radiomorphometric indicators of the mandible in the assessment of bone mineral density in historical populations”

written under the supervision of Prof. Sławomir Kozieł, PhD
and **assistant supervisor** Dr. Anna Spinek

The doctoral dissertation was completed at the Department of Anthropology of the Ludwik Hirszfeld Institute of Immunology and Experimental Therapy of the Polish Academy of Sciences.

This review is based on a letter dated October 31, 2025, informing that the Scientific Council of the Ludwik Hirszfeld Institute of Immunology and Experimental Therapy, at its 223rd meeting on October 9, 2025, appointed me as a reviewer of the doctoral dissertation in the field of exact and natural sciences, in the discipline of biological sciences.

Title and subject of the dissertation

Joanna Heuchert, MA, submitted her doctoral dissertation in the form of a monograph entitled: “*Radiomorphometric indicators of the mandible in the assessment of bone mineral density in historical populations.*” The title of the thesis is correctly formulated, unambiguous, and accurately reflects both the substantive scope of the research and the methodological approach used. The content of the thesis is fully consistent with its title.

The thesis focuses on assessing the possibility of using radiomorphometric indicators of the mandible as non-invasive tools for indirect assessment of bone mineral density (BMD) in historical populations. The analysis is based on extensive anthropological, odontological, radiological, and densitometric studies conducted on 197 individuals from two skeletal series: 62 individuals from medieval Milicz (12th-14th century AD) and 135 individuals from early modern Wrocław (16th-18th century AD).

The research problem undertaken by the doctoral candidate is both relevant and scientifically significant. The issue of bone loss and its biological and environmental determinants in ancient populations constitute an important component of reconstructing health status, quality of life, and biocultural adaptation processes of humans. At the same time, the use of mandibular radiomorphometry in bioarchaeological research remains a relatively poorly understood area, especially with regard to the populations of Central Europe. Thus, the subject of the dissertation is in line with current research trends in the biological sciences, biological anthropology, bioarchaeology, and medical sciences, and possesses clear cognitive and comparative value.

The scientific merit of the dissertation, as well as of its principal chapters, should be rated highly. The study is characterized by methodological maturity, clearly formulated research objectives, and a consistent analytical framework. The results obtained are original and constitute a significant contribution to current knowledge regarding the applicability of radiomorphometric methods in the assessment of skeletal mineral status in historical populations. Owing to their substantive quality and methodological rigor, the results are suitable for publication in peer-reviewed international journals. Moreover, the empirical material collected represents a valuable and lasting contribution to comparative studies of skeletal series from Poland.

1. Assessment of the layout and structure of the dissertation

The reviewed dissertation comprises 141 pages and follows a structure typical of empirical research, including chapters entitled: Introduction, Objectives of the Study, Materials and Methods, Results, Discussion, and Conclusions. The work is supplemented by an extensive bibliography, as well as lists of tables (32) and figures (10), and includes abstracts in both Polish and English.

The structure of the dissertation is logical, clear, and adequate for the achievement of the research objectives. The individual chapters form a coherent whole, allowing the reader to smoothly familiarize themselves with the research material, the methodology used, the course of the analyses, and the results obtained.

Introduction and objectives of the work

The Introduction represents a strong element of the dissertation. Its principal merits include consistency with the research objectives, an extensive and up-to-date review of the literature (over 200 references), a sound understanding of the interdisciplinary research context, and a competent presentation of contemporary instrumental and analytical methods relevant to bioarchaeological research. The author demonstrates very good knowledge of current research in biological anthropology, paleopathology, clinical osteology, metabolic medicine, and osteoporosis diagnostics.

At the same time, the chapter is highly ambitious and presents a very broad interdisciplinary perspective on bone loss in historical populations. In several places, however, it exceeds the typical scope of an introductory chapter and adopts the character of a review article. In particular, extensive discussions of clinical pathophysiology and contemporary epidemiology of osteoporosis somewhat obscure the central research problem and weaken the emphasis on the specific methodological gap addressed by the dissertation. The text is characterized by high factual accuracy and a careful, academic style.

The key issues related to mandibular radiomorphometry appear relatively late in the Introduction and would benefit from earlier placement, as they constitute the conceptual core of the study. Furthermore, the research gap is not formulated explicitly in a single, clearly defined section, but rather dispersed throughout the chapter. A more concise and focused presentation of the state of the field, followed by a clearly articulated research gap, would strengthen the argumentative structure.

Despite these remarks, the Introduction provides a solid foundation for the study and clearly demonstrates the author's extensive erudition and substantive preparation. The research objectives are formulated clearly, logically, and in a fully operationalized manner, and they provide a sound basis for the subsequent analyses.

In many places in this chapter, the narrative style changes (from textbook to analytical), overly emotional language is used (“exceptionally,” “remarkably”), and definitions appear that are not necessary in the context of the work. The introduction should be slightly shorter, as the current length makes it difficult to follow the narrative.

Subchapters 4.7.1–4.7.5 (environment, nutrition, physical activity, culture, demography) could be shortened and synthetically linked to *local* issues in Lower Silesia.

Proposed abbreviation: "*Despite the development of BMD assessment methods (...), mandibular radiomorphometric indices have not yet been systematically applied to large archaeological populations in Central Europe. The lack of comparative data, measurement standards, and studies linking mandibular indicators with femoral BMD constitutes a significant methodological gap, which this work fills.*"

The pathophysiology of osteoporosis, biological mechanisms, global epidemiology, and contemporary clinical data are discussed extensively. However, the specificity of the medieval and modern populations of Lower Silesia and the uniqueness of the use of material from Wrocław and Milicz are not sufficiently emphasized. It is not explained why the mandible is the most accessible and diagnostically valuable in archaeological analyses, nor which features of the mandible are taphonomically stable and suitable for measurement.

The introduction ends before the objectives, without a synthetic emphasis on the significance of the research.

In summary, this chapter needs to be shortened and its content better condensed (especially the medical and general biological sections). The aforementioned research gap should be highlighted more strongly and the choice of methods should be more clearly justified. The narrative should be better organized, with an emphasis on clarity and hierarchy of arguments, as well as stylistic consistency and reduction of repetitions. Despite these comments, the chapter provides a very solid introduction to the subject, demonstrates the author's extensive erudition and substantive preparation, and the research objectives presented are clear, logical, and allow for the continuation of work at a high academic level.

The objectives of the work have been formulated clearly, logically, and in a fully measurable manner. They are directly related to the research problem presented and provide a solid basis for further analysis.

In the Materials and Methods chapter, the author presents two skeletal series originating from medieval Milicz and early modern Wrocław, derived from osteological collections curated at the Department of Anthropology of the Hirszfeld Institute of Immunology and Experimental Therapy of the Polish Academy of Sciences. The chapter is extensive, well structured, and methodologically sound.

In this chapter, the following deserve special recognition: a careful description of the archaeological context and sample selection criteria, a very extensive and mature statistical section, consideration of technical measurement error (TEM), ICC coefficients, and Bland - Altman analyses, the clear description of mandibular radiomorphometric indices, and the conscious approach to the problems of calibration and standardisation of measurements performed on different devices.

The methodological descriptions are detailed and supported by illustrative material, enabling the reader to fully understand the applied procedures. The author demonstrates thorough preparation for conducting the analyses and a very good command of the relevant literature. The scope of the dataset is considerable, encompassing nearly three thousand observations derived from mandibular and femoral measurements, which provides a solid empirical basis for addressing the research objectives. In my opinion, this is a very well-prepared and well-written chapter in the dissertation. The author has demonstrated a very good knowledge of the literature on the subject. The designated mandibular radiomorphological indicators have been thoroughly explained and illustrated, as have the densitometric measurements performed on the right or left femur. This demonstrates the doctoral student's thorough and excellent preparation for conducting the observations. I believe that the statistical methods used are adequate and fully sufficient for the issue analyzed, which the author collected in a table and presented at the end of this 13-page chapter.

The data from the observations and studies of 197 mandibles belonging to two skeletal series provided a good reference point for the tested research objective of the dissertation on the use of nine selected radiomorphometric indicators of the mandible as non - invasive tools for indirect assessment of bone mineral density (Bone Mineral Density, BMD) in historical populations. The author conducted research on the mandibles of two populations that did not constitute communities living in exactly the same area, certainly in different temporal and environmental conditions. A total of 197 mandibles is a large collection, but their numbers in individual age and gender groups are sometimes small (Table 2). Such small subsets are not

sufficient, for example, to assess bone density in the oldest age groups in the Milicz series. The author rightly addressed the resulting reservations in the discussion chapter.

Comments on the Materials and Methods chapter.

The following methodological observations are offered to improve clarity and reproducibility; all points are relevant and should be considered:

1. Sample and archaeological context

1. The description of the archaeological context is detailed, but a brief discussion of demographic selectivity (underrepresentation of children and the elderly) and its potential impact on mandibular parameters and bone density interpretation is recommended.
2. A summary table of bone preservation in both populations would facilitate assessment of sample quality and comparability.
3. The age assessment based on cranial suture fusion has limited precision; it is advisable to note that the results are indicative rather than exact.
4. Clarify the inclusion criterion described as “cranium condition allowing stable positioning on a tripod,” specifying which defects or deformities led to exclusion.
5. Justify the requirement for “very good preservation of the mandible,” emphasizing its central role in radiomorphometric analyses.

2. Imaging and radiographic procedures

6. The use of modeling clay for stabilisation requires specification of the material type, as mineral composition can affect X-ray absorption.
7. The use of lard slices wrapped in plastic as a soft-tissue substitute is uncommon; a brief justification and note on exposure control testing are recommended.
8. Two panoramic devices (Kodak vs. Vatech) may introduce geometric distortion; clarify whether magnification and deformation differences were corrected and provide calibration data.
9. Describe whether positioning relative to the Frankfurt plane accounted for skeletal deformations, and if deformation compensation was applied.
10. Specify whether the Weasis software automatically corrected for image magnification and whether calibration relied on an internal marker (e.g., metal scale).

3. Densitometry and measurement repeatability

11. Repeatability testing on 30% of the sample is beneficial, but the standard in osteological literature is 50–100%; a brief justification for 30% is recommended.
12. Measurements were performed using two different densitometers; clarify comparability, calibration differences, photon energies, and factory standards, ideally in a table or short paragraph.
13. Include a precision error assessment (e.g., at least 10 repetitions of a single object), as is standard in densitometry.
14. For femoral measurements, report whether positioning repeatability was verified (e.g., repositioning error).

4. Dental and statistical considerations

15. When assessing caries, indicate whether optical magnification or spot lighting was employed, as this significantly affects detection of microdefects.
16. In evaluating CEJ–AC periodontitis, note whether the attrition grade of heavily worn teeth was considered to avoid misinterpretation.
17. The statistical section is very robust; consider reporting whether a power analysis was performed or explain why it was not feasible in archaeological material.
18. Provide exact numbers for age and sex analyses, as unequal subgroup sizes may affect detection of significant effects.
19. In regression analyses, clarify whether interactions between sex and age were tested, which can be important in BMD studies.

However, these comments are supplementary and do not undermine the overall high quality of the methodology presented.

To summarize the content of the work presenting the Material and Methods, I would like to commend the doctoral student for her good knowledge of the research issues and methods used in anthropology, radiology, paleopathology, and her appropriate use of research material. The author's significant effort in this part of the work should be emphasized. I would like to point out that the bone material is very extensive and, considering the detailed and technically objective research methods, I would like to note that the author devoted a great deal of time, attention, and energy to conducting and compiling the research.

The Results chapter is one of the most extensive in the doctoral dissertation. The author demonstrates a high level of methodological competence and a mature approach to the analysis of biological data. The data are presented in a transparent manner, with a structure corresponding to the individual research questions.

The statistical procedures used, the manner of presenting the results, and the scope of their interpretation are fully adequate to the nature of the material and the objectives of the work. Particularly noteworthy is the visible attention to clarity, the consistent use of the scheme: numerical description - statistical reference - biological interpretation, as well as the correct consideration of the effect size and avoidance of overinterpretation of the results.

I highly appreciate the correct use of basic statistical tests (χ^2 , t-test, Levene, Shapiro-Wilk, Pearson and Spearman correlation, multiple regression analysis), skillful differentiation between parametric and non-parametric analyses, and correct use of p values, df, r, Cohen's d, β , ICC, TEM, VIF, etc.

The author makes correct use of basic statistical tests (χ^2 , t-test, Levene, Shapiro-Wilk, Pearson and Spearman correlation, multiple regression analysis), differentiates skillfully between parametric and non-parametric analyses, and correctly reports p values, degrees of freedom, effect sizes (Cohen's d, Cramer's V, R^2), β coefficients, ICC, TEM, VIF, and other relevant parameters. Normality (Shapiro–Wilk) and homogeneity of variance (Levene) tests are performed in the correct order, and Bonferroni correction is applied appropriately for multiple comparisons. Correlations are interpreted using the correct coefficient depending on the distribution of variables (Pearson r vs. Spearman ρ).

The interpretation of the results is accurate and consistent with both statistical principles and biological reasoning. For example, the observed relationships between increasing age and decreasing MCW and BMD are correctly described. The integration of effect size with biological interpretation enhances the quality of the work. Importantly, correlations are not interpreted causally.

All abbreviations and anatomical terms (MCW, MR, GA, AA, AD, AI, etc.) have been used correctly in accordance with the nomenclature used in radiomorphometric and dental-anthropological literature. The correct BMD classification (Neck, Ward's, Trochanter, Total) has been used.

It is worth appreciating that the author uses full names when introducing an abbreviation for the first time (e.g., MCW – mandibular cortical width), which facilitates reading.

From an anthropological perspective, the description of the material, the classification of age and sex, and the presentation of morphometric data are correct, and the biological language is appropriate for the nature of the research on osteological material. The author's knowledge of the biological background of the results is very good – she understands the biomechanical and hormonal basis of differences (sex, age, environment). The interpretation of the results is carried out with great caution and awareness of the limitations of the material. The author does not overinterpret – correlations are not treated causally, and biological conclusions are formulated with due caution. The ability to integrate statistical results with the biological and anthropological context is clearly evident, allowing for a reliable presentation of the dynamics of biological processes revealed in the osteological material.

In particular, the doctoral student correctly interpreted the observed decline in MCW and BMD with age. She accurately explained sexual dimorphism by referring to hormonal and biomechanical causes, and presented the differences between the medieval and early modern populations in an adequate environmental and socio-cultural context.

The style of the work is consistent, balanced, and maintained at a high scientific level. The author uses precise language, free of colloquialisms, and the numerical records are essentially correct in formal terms. Each subchapter is clearly linked to a specific research question, which makes the structure of the chapter perfectly readable.

The chapter is scientifically sound and written in a style appropriate for a doctoral dissertation in human biology/physical anthropology, with elements of medical science.

Comments and Recommendations – Results

The following points are suggested to improve clarity, consistency, and reproducibility of the chapter:

1. Statistical reporting

1. In several χ^2 tests, degrees of freedom (df) and sample sizes (n) are not explicitly provided; these should be added to the tables.

2. Fisher's exact tests should include either exact p-values or a note "n = x, expected < 5."
3. Correlation type (Pearson r vs. Spearman ρ) should be introduced consistently, with explanation of choice based on variable distribution.
4. Regression tests should report detailed statistics (F, SE, t values of individual predictors), at least in the tables.
5. The VIF notation "VIF(1/(2Df))" is unclear; VIF should be reported simply as a numeric value.
6. P-values currently written as "p = 0.000" should be corrected to "p < 0.001."

2. Presentation of results

7. In sections 7.2 and 7.3, some passages mix raw results with biological interpretation; separate clear presentation of data from discussion.
8. Correlation figures (Figs. 7–8) should include the number of observation pairs (n).
9. Include Durbin–Watson test results in regression analyses to assess residual autocorrelation.
10. MCI and AMTL indices should be introduced with full names when first mentioned (Mandibular Cortical Index; Antemortem Tooth Loss).
11. Standardize plural usage: "indices" instead of "index values" when referring to multiple measures.
12. Standardize terminology for BMD, e.g., TotBMD vs. Total BMD.

3. Style and clarity

13. Avoid literal repetition of table content; summaries should focus on trends, limit values, p-values, and effect sizes.
14. Some phrases are overly formal or repetitive ("it is worth noting," "the highest mean value is recorded"); use concise scientific register ("notably," "the greatest mean was observed").
15. Include sample size (n) and variance information consistently in the text.
16. Standardize terminology for correlation strength ("strong/moderate/low") using reference criteria (e.g., Cohen's rules).

The Results chapter is coherent, methodologically robust, and scientifically sound. Minor editorial adjustments related to statistical reporting, clarity, and style would further enhance readability and reproducibility.

The Discussion chapter is extensive, multi-threaded, and well-grounded in the context of the literature on the subject. The author consistently discusses the results in relation to the five main research questions, which is a great advantage in terms of logical composition. The discussion contains numerous references to clinical and bioarchaeological studies, demonstrating a very good understanding of the international literature.

A major strength of this chapter is its clear structure, with each issue (gender, age, and population differences, etc.) discussed in a separate section. The author uses appropriate scientific language, which makes the style of the discussion consistent with biological and medical literature. The interpretations of the results are critical rather than merely descriptive. The doctoral student attempts to justify the reasons for the observed differences, taking into account biological and environmental factors. This chapter features very well-chosen sources, both classic (Mays, Armelagos, Brickley, Looker) and contemporary (e.g., Dutra 2004, Bozdog & Sener 2015, Looker 2012). The morphological differences between AA and AD are very accurately identified and correctly interpreted with biomechanical justification. The author draws attention to the biological rationale for the differences (chewing muscle strength, attachment points, mechanical loads).

However, the potential influence of sex hormones is treated somewhat superficially. For instance, there is no discussion of the role of estrogens in mandibular remodeling or calcium metabolism. Similarly, the potential influence of diet and physical activity patterns, which could have contributed to sexual dimorphism in historical populations, is minimally addressed. While indices such as MCW, AD, and AA are interpreted correctly, there is a lack of in-depth mechanistic explanation for why some indices do not display sexual dimorphism.

Regarding age-related changes, the author provides an excellent synthesis of clinical research (Devlin & Horner 2002; Nagi 2014; Kiswanjaya 2025). The behavior of MCW, GI, AI, and MR indices with age, as well as the decline in BMD in Ward's triangle, are accurately interpreted in connection with trabecular tissue remodeling. Nevertheless, gender differences in the rate of bone loss with age are insufficiently discussed. Specifically, the acceleration of BMD loss in postmenopausal women is not addressed, which is crucial for interpreting population-level patterns. Additionally, the discussion does not clearly separate biological effects from potential measurement errors related to small sample sizes in older individuals from Milicz.

The section discussing the relationship between mandibular indices and BMD is well linked to the clinical literature (Balto 2018; Camargo 2017; Abdinian 2023), and the use of regression analysis (β , p , R^2) enhances the statistical rigor of the discussion. The explanation of the differences in correlation signs for AD and MCW demonstrates a solid understanding of jaw mechanics. However, the discussion lacks deeper consideration of inter-population differences - for example, why the AI–BMD relationship is stronger in Milicz - and does not address potential errors from radiograph orientation, device calibration, or densitometry standardization, which could affect correlations.

The analysis of oral health and skeletal relationships is commendable, particularly the comparison of enamel hypoplasia with BMD as a marker of early childhood stress - a rare and valuable approach. The author distinguishes between local effects (AI - tooth loss) and systemic effects (BMD) and compares findings with contemporary studies (Nicolopoulou-Karayianni 2009; Penoni 2017). This section could be strengthened by considering interpretative limitations, including potential genetic influences on enamel hypoplasia, diagenetic effects, and errors in macroscopic classification.

Comparative analyses between populations (Milicz vs. Wrocław) are conducted at a high level. Osteometric results are effectively integrated with socio-economic and nutritional context, and the paradox of “higher BMD and lower MCW” is well justified by age structure and urban health conditions (vitamin D deficiency, infections, overcrowding), with accurate references (Brickley, Mays, Ives, Duma). Nevertheless, hypotheses regarding diet are not supported by isotopic or environmental data, and the discussion would benefit from quantitative indicators of urbanization and economic conditions.

In summary, the Discussion chapter is well-structured, accurate, and integrates perspectives from biological anthropology, medicine, and osteometry. It demonstrates the author’s extensive scientific preparation and knowledge of current research trends. Further improvements could include: a more detailed explanation of biological mechanisms (hormones, calcium metabolism, biomechanics), deeper statistical interpretation (prediction models, variance analysis, test power), and expanded discussion of interdisciplinary research potential (e.g., isotopes, microtomography, ancient DNA).

The Conclusions correspond closely to the research objectives. Mandibular radiomorphometric indices are confirmed as valuable, although secondary, indicators of

skeletal health. Their use alongside classical osteological and bioarchaeological methods offers new opportunities for reconstructing human health, diet, and biological adaptation in the past. The author demonstrates that non-invasive mandibular radiomorphometric indicators reflect overall skeletal mineral status in historical populations. The combination of mandibular morphometry with direct BMD measurements (DXA) represents a unique bioarchaeological approach, providing insights into bone remodeling, sexual differentiation, and aging under different environmental conditions.

The results obtained allow for a better understanding of the processes of bone remodeling, sexual differentiation, and aging in various environmental conditions of the past.

The bibliography is extensive, current, and interdisciplinary, comprising over 300 references, with ~35% published between 2015–2025, and a balanced inclusion of Polish and international sources (JCR and Scopus-indexed journals). Peer-reviewed, high-impact sources dominate, and systematic reviews and meta-analyses are appropriately utilized. Suggested minor improvements include: reducing redundancy in clinical osteoporosis literature, clarifying historical citations (Acsádi & Nemeskéri 1970; Dewey et al. 1969) for methodological context, and including studies on bone fragmentation and diagenesis (e.g., Kendall et al. 2018) for assessing reliability of BMD measurements in archaeological material. The bibliography forms a coherent, interdisciplinary theoretical basis for analyses combining radiological diagnostics, physical anthropology, and research on skeletal health in the past. It is a model example of a comprehensive literature base for this type of scientific research. A good balance is maintained between Polish-language and international literature (approx. 10–15% of items from Polish journals and scientific publications). Most of the sources come from recognized international journals from the JCR and Scopus lists (including *Osteoporosis International*, *American Journal of Physical Anthropology*, *Dentomaxillofacial Radiology*, *Journal of Bone and Mineral Research*, *Nature Reviews Endocrinology*). Peer-reviewed works with a high impact factor dominate, which increases the scientific value of the bibliography. The extensive use of systematic reviews and meta-analyses (Calciolari et al. 2015; Beck et al. 2017; Bertilsson et al. 2022) is also commendable. Despite the high quality of the selection, the following additions and updates could be considered: Limiting repetitions of literature on clinical osteoporosis (e.g., Eastell, Drake, Bilezikian, Bouillon) - a representative selection of the latest sources is sufficient, without an excess of related topics.

Clarification of historical citations - items such as Acsádi & Nemeskéri (1970) or Dewey et al. (1969) should be treated as classic works, but with an emphasis on their methodological and historical nature, not empirical. Addition of works on bone fragmentation and diagenetic changes, e.g., the study by Kendall et al. (2018), in the context of the reliability of BMD measurements in archaeological material.

2. Assessment of whether the doctoral dissertation presents an original solution to a scientific problem.

The dissertation constitutes an original contribution to biological sciences. The research objectives, methodology, and results provide novel insights into the use of mandibular radiomorphometric indices for assessing skeletal health in historical populations.

3. Candidate's theoretical knowledge and independent research ability:

The work demonstrates a high level of interdisciplinary knowledge in physical anthropology and medical sciences. The candidate shows the ability to independently design and execute research, analyze data, and interpret results critically.

Overall evaluation:

I consider the dissertation outstanding and recommend that Ms. Joanna Heuchert be awarded a distinction.

I hereby declare that the doctoral dissertation meets the requirements specified in Article 187 (1)-(4) 1-4 of the Act on Higher Education and Science (i.e. Journal of Laws of 2024, item 1571, as amended) and I request that the doctoral student be admitted to the further stages of the procedure for awarding a doctoral degree in the discipline of biological sciences.

Szczecin, 6.01.2026

