UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

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Avaliação da confiabilidade da fotogrametria e de estruturas craniofaciais como metodologias alternativas no dimorfismo sexual de crânios humanos na Antropologia forense. Revisões sistemáticas

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Tese apresentada à Faculdade de Odontologia de Bauru da Universidade de São Paulo para obtenção do título de Doutora em Ciências no Programa de Ciências Odontológicas Aplicadas, na área de concentração Biologia Oral, Estomatologia, Radiologia e Imaginologia.

Orientador: Prof. Dr. André Luís Shinohara

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Dedico esta tese a **Deus**, aos meus pais **Ana Lucia** e **Joaquim Carlos**, ao meu irmão **Antonio**, ao meu namorado **Thiago** e aos meus **amigos** que sempre estiveram ao meu lado.

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Avaliação da confiabilidade da fotogrametria e de estruturas craniofaciais como metodologias alternativas no dimorfismo sexual de crânios humanos na Antropologia forense. Revisões sistemáticas. Tese (Doutorado) – Faculdade de Odontologia de Bauru, Universidade de São Paulo, Bauru, 2023.

Resumo

Este trabalho objetivou realizar duas revisões sistemáticas com as seguintes propostas: 1) estabelecer se a fotogrametria de crânios secos é confiável como método para estimar o sexo na identificação humana, e 2) e avaliar o grau de confiabilidade na determinação do dimorfismo sexual do processo mastóide comparando-o a outras estruturas dimórficas. As Revisões Sistemáticas foram registradas no PROSPERO (CRD420223 e CRD 42023395167, respectivamente) e seguiram as diretrizes dos Itens de Relatório Preferenciais para Revisões Sistemáticas e Meta-análise (PRISMA). As buscas foram realizadas nas bases de dados eletrônicas PubMeb, Scopus, Web of Science, Embase, Web of Science, Clinical Trials e Cochrane Library e nos bancos de dados da literatura cinza. Artigo 1: A concordância Kappa apresentou nível de aprovação de k=0,93. Esta revisão sistemática analisou 11 estudos *ex-vivo* publicados entre 2001 e 2021. O risco de viés foi considerado baixo em 8 dos estudos e alto em 3 estudos. Com base nesta revisão sistemática, pode-se concluir que o método da fotogrametria é viável e confiável na identificação do dimorfismo sexual. Nos resultados do Artigo 2: A concordância Kappa apresentou nível de aprovação de k=0,93. Esta revisão sistemática analisou 12 estudos *ex-vivo* publicados entre 2008 e 2020. O risco de viés foi considerado baixo em 8 dos estudos e alto em 4 estudos. Com base nesta revisão sistemática, pode-se concluir que, mesmo com as limitações do presente estudo, análises quantitativas e qualitativas são essenciais na identificação sexual de crânios humanos, e diferentes estruturas anatômicas podem ser usadas como referências, além do processo mastóide, com alta confiabilidade e precisão, entre eles; glabela, perfil frontal, arco superciliar, largura bizigomática, comprimento craniano máximo e altura nasal.

Palavras-Chave: Antropologia forense; Identificação humana; Fotogrametria; Mastóide; Características sexuais; Revisão sistemática.

Evaluation of the reliability of photogrammetry and craniofacial structures as alternative methodologies in the sexual dimorphism of human skulls in forensic anthropology. Systematic reviews. Thesis (Doctorate) – Faculty of Dentistry of Bauru, University of São Paulo, Bauru, 2023.

Abstract

This work aimed to carry out two systematic reviews with the following proposals: 1) to establish whether the photogrammetry of dry skulls is reliable as a method to estimate sex in human identification, and 2) and to evaluate the degree of reliability in determining the sexual dimorphism of the mastoid process comparing it to other dimorphic structures. Systematic Reviews were registered in PROSPERO (CRD420223 and CRD 42023395167, respectively) and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Searches were performed in electronic databases PubMeb, Scopus, Web of Science, Embase, Web of Science, Clinical Trials and Cochrane Library and gray literature databases. Article 1: The Kappa concordance presented an approval level of k=0.93. This systematic review analyzed 11 *ex-vivo* studies published between 2001 and 2021. The risk of bias was considered low in 8 of the studies and high in 3 studies. Based on this systematic review, it can be concluded that the photogrammetry method is viable and reliable in identifying sexual dimorphism. In the results of Article 2: The Kappa concordance showed an approval level of k=0.93. This systematic review analyzed 12 *ex-vivo* studies published between 2008 and 2020. The risk of bias was considered low in 8 of the studies and high in 4 studies. Based on this systematic review, it can be concluded that, even with the limitations of the present study, quantitative and qualitative analyzes are essential in the sexual identification of human skulls, and different anatomical structures can be used as references, in addition to the mastoid process, with high reliability and accuracy, among them; glabella, frontal profile, superciliary arch, bizygomatic width, maximum cranial length, and nasal height.

Keywords: Forensic anthropology; Human identification; Photogrammetry; Mastoid; Sex characteristics; Systematic review.

Lista de Tabelas

TABELAS - ARTIGO 1

TABELAS - ARTIGO 2

Lista de Figuras

Figura - ARTIGO 1

Figura - ARTIGO 2

SUMÁRIO

ANEXOS

1. INTRODUÇÃO E JUSTIFICATIVA

A função da antropologia forense visa construir um perfil biológico ao se deparar com restos humanos não identificados, a fim de realizar a identificação humana através da avaliação do sexo, idade e ancestralidade do indivíduo (BEREZOWSKI; ROGERS; LISCIO, 2021; BIANCALANA *et al.*, 2015; ZILIO, FERNANDA; BASUALDO, ALEXANDRE; CRUZ, 2014). A avaliação do sexo é a mais importante e deve ser realizada primeiro, pois as análises subsequentes de idade e ancestralidade são fatores dependentes de uma análise precisa da avaliação sexual (BEREZOWSKI; ROGERS; LISCIO, 2021; PETAROS *et al.*, 2015a).

Sempre que possível, deve-se utilizar o esqueleto em sua totalidade para proceder com a identificação de uma ossada (NUNES; GONÇALVES, 2014a). Entretanto, comumente parte do esqueleto, fragmentos ósseos carbonizados ou não, e ossadas misturadas em uma vala são encontrados, tornando esta tarefa mais complexa, e exigindo que qualquer estrutura possível seja utilizada no processo, devendo o perito utilizar o máximo de estruturas que permitam a identificação (NUNES; GONÇALVES, 2014a).

Como nem sempre é possível trabalhar com o esqueleto completo para fazer a identificação da ossada encontrada, os ossos são inicialmente estudados de maneira isolada quando encontrados. A pelve é o osso de maior confiabilidade na determinação do sexo com 95% de precisão, mas nem sempre é encontrada íntegra, seguido do crânio com 92% de confiabilidade, e quando possível, a avaliação de ambos permite uma precisão de 98%. Estas duas estruturas anatômicas são as mais utilizadas para a identificação sexual devido as suas características peculiares diferentes entre os sexos, possibilitando uma diferenciação por meio do estudo de seus acidentes anatômicos (MAHAKKANUKRAUH *et al.*, 2016; NUNES;

GONÇALVES, 2014b; OLIVEIRA *et al.*, 2012; PAIVA; SEGRE, 2005; THUANTHONG; SUDWAN, 2019).

Para estabelecer os processos comparativos em antropometria é necessário determinar os pontos anatômicos de referência, independente da técnica e/ou sistema de análise, direta ou indireta, manual ou digital (NUNES; GONÇALVES, 2014b). A antropometria craniofacial é crucial na Odontologia Legal, pois auxilia no reconhecimento de dados que ajudam na identificação humana, para isso ela conta com a cranioscopia e craniometria (ALMEIDA *et al.*, 2010; BIANCALANA *et al.*, 2015; CASADO, 2017; FATAH *et al.*, 2014; NUNES; GONÇALVES, 2014b; PETAROS *et al.*, 2015a).

A cranioscopia é o estudo analítico visual das estruturas cranianas, sendo muitas vezes subjetiva, pois depende da acurácia do examinador, sendo esta técnica baseada na inspeção visual, na observação e descrição da forma dos ossos do crânio (BIANCALANA *et al.*, 2015; NUNES; GONÇALVES, 2014b; PETAROS *et al.*, 2015a). O crânio masculino apresenta dimensão e massa maiores, os dentes também mais robustos, fronte mais inclinada para trás, arcos superciliares e glabela mais proeminentes, articulação mais angulada entre o osso frontal e nasal, bordas supraorbitais romboides, processos mastoides e estiloides mais proeminentes, côndilo occipital e forame magno maiores, mandíbula espessa e robusta com corpo alto, ângulo mandibular menos obtuso, e cristas de inserção muscular mais pronunciadas. Já o crânio feminino é menor e apresenta morfologia mais delicada, fronte vertical, glabela e arcos superciliares pouco salientes, articulação frontonasal curva, bordas supraorbitais cortantes, processos mastoides e estiloides menos desenvolvidos, côndilo occipitais e forame magno menores, mandíbula achatada e menos robusta (ALVIM; PEREIRA, 1979; NUNES; GONÇALVES, 2014b; VANRELL; CAMPOS, 2010).

Já a craniometria é a medição dos ossos do crânio, sendo dividido por planos que delimitam suas porções anterior, posterior, superior, inferior, direita e esquerda; após a delimitação dos planos, são demarcados os pontos craniométricos e após obter as medidas, realiza-se a comparação com um banco de dados, essa comparação pode ser manual ou com o uso de softwares específicos (ALMEIDA *et al.*, 2015; HOWELLS, 1996; VANRELL; CAMPOS, 2010; VAZ; BENFICA, 2008). Os crânios masculinos em geral são maiores do que os femininos, além disso podem ser diferenciados de acordo com a capacidade craniana, peso, diâmetro ântero-posterior, diâmetro transverso, altura craniana, largura bizigomática e espessura óssea (ALMEIDA *et al.*, 2010). No entanto, os métodos quantitativos existentes não apresentam, em sua maioria, um bom índice de confiabilidade (BIANCALANA *et al.*, 2015; MACHADO *et al.*, 2005). Em adicional, muitos trabalhos encontrados na literatura científica utilizam amostra estrangeira limitando suas aplicabilidades na população brasileira, além do banco de dados obter dados desatualizados e ter como base características de americanos e europeus. (ALMEIDA *et al.*, 2010).

A população brasileira apresenta um fator que dificulta a identificação de forma confiável também nos métodos qualitativos devido a miscigenação racial, pois a morfologia do crânio pode ser influenciada pelas interações gênicas, além da influência de fatores ambientais (BIANCALANA *et al.*, 2015).

O crânio apresenta aproximadamente 5000 medidas cranianas entre elas estruturas com baixo ou nulo dimorfismo sexual (MAHAKKANUKRAUH *et al.*, 2016). As estruturas cranianas com grande relevância no dimorfismo sexual são: a glabela, a crista nucal, a margem orbitária, o processo mastóide e a proeminência mentual quando a mandíbula estiver presente. (AJANOVIĆ *et al.*, 2019; GARVIN; SHOLTS; MOSCA, 2014; KRÜGER *et al.*, 2015; MAGDA BANIĆ, ŽELJANA BAŠIĆ, 2016; SOFICARU *et al.*, 2014; WALKER, 2008).

Entretanto, muitos artigos são encontrados utilizando o processo mastóide como estrutura de análise, desde o século passado até os dias de hoje devido as suas características dismórficas, e também devido a sua localização e robustez sendo possível ser analisado mesmo em crânios fragmentados e queimados, tornado uma estrutura padrão ouro em relação ao dimorfismo sexual (DE PAIVA; SEGRE, 2003; PETAROS *et al.*, 2021).

No entanto, pode-se encontrar estruturas com variações anatômicas que apresentam características contraditórias ou ambíguas em relação ao dimorfismo sexual (GARVIN; SHOLTS; MOSCA, 2014). Há evidências que a diminuição da ação muscular, desnutrição grave e a atrofia pode diminuir a precisão desses métodos (SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2008). Isso sugere que as influências intrínsecas e extrínsecas podem influenciar diferentes traços cranianos, e por isso deve-se avaliar mais que uma estrutura para melhor precisão e confiabilidade (GARVIN; SHOLTS; MOSCA, 2014). Das cinco características mais utilizadas no método visual a fim de determinar o dimorfismo sexual, a crista nucal, processo mastóide e glabela são afetados por forças biomecânicas porque são locais de inserções musculares para funções como movimento das sobrancelhas, cabeça e pescoço (GODDE; THOMPSON; HENS, 2018).

Para estabelecer os processos comparativos em antropometria é necessário determinar os pontos anatômicos de referência, independente da técnica ou sistema de análise, direta ou indireta, manual ou digital (NUNES; GONÇALVES, 2014b). Esses pontos são denominados de craniométricos, para crânio, e cefalométricos para face (ALVIM; PEREIRA, 1979; VANRELL; CAMPOS, 2010). Assim como selecionar as estruturas anatômicas a serem analisadas morfologicamente ou seja pela análise cranioscópica independentemente do método ou sistema de análise (ALVES *et al.*, 2020; KRÜGER *et al.*, 2015; MAGDA BANIĆ, ŽELJANA BAŠIĆ, 2016; SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2009).

Antigamente, os antropometristas realizavam o processo manualmente, de forma direta sobre as estruturas visíveis do crânio, mas com o desenvolvimento tecnológico, os raios-X, tomógrafo computadorizado e da ressonância magnética, além do aumento de dispositivos capazes de produzir imagens, houve possibilidades de metodologias alternativas à medição direta (NUNES; GONÇALVES, 2014b).

A cefalometria é utilizada principalmente por ortodontistas para classificar, comparar e quantificar dados da morfologia dento-craniofacial por meio de pontos anatômicos de referência e estruturas visualizáveis em telerradiografias, a fim de analisar o crescimento e desenvolvimento facial (CARDOSO *et al.*, 2005).

A técnica cefalométrica pode apresentar alguns erros, com por exemplo, as imagens radiográficas podem sofrer distorção; além do erro do examinador ao determinar os pontos anatômicos de referência na telerradiografia; a experiência do examinador é um fator importante na diminuição dos erros nas variações de medidas cefalométricas em relação às médias (LAU; COOKE; HÄGG, 1997). Alguns estudos tentam analisar e quantificar os erros da técnica, mas mesmo assim os resultados destas pesquisas não garante total confiabilidade dos métodos de medição (DE ALBUQUERQUE JUNIOR, 1996; LAU; COOKE; HÄGG, 1997; MARTINS, 1993).

Por serem as telerradiografias inadequadas para área de identificação e reconhecimento facial forense, pois são utilizadas como base de comparação imagens faciais em norma frontal por meio dos registos civil e criminal (GRUBER; KAMEYAMA, 2001), os profissionais do campo forense utilizam as informações cefalométricas como auxílio no protocolo de identificação humana por meio do conjunto de valores angulares, lineares ou proporções estabelecidas para diferenciar uma pessoa das demais (NUNES; GONÇALVES, 2014b).

Outras maneiras de identificar o crânio e de determinar o dimorfismo sexual são por meio de seu escaneamento, por meio das imagens de ressonância magnética, ou tomografia computadorizada. Estas técnicas permitem obter cortes em vários ângulos e espessuras, e ao acrescentar essas imagens em um software específico é possível obter imagens do crânio completo (DEDOUIT *et al.*, 2014; DINIZ; SANTOS; MARTIN, 2008; ROCHA; RAMOS; CAVALCANTI, 2003). O escaneamento pode ser feito também por meio de fotografias ou filmagens, mas a fim de padronizar deve-se tomar alguns cuidados como a iluminação, distância, posicionamento, pois são realizadas várias tomadas fotográficas sequenciais de diversos pontos e ângulos (DEDOUIT *et al.*, 2014; DINIZ; SANTOS; MARTIN, 2008; ROCHA; RAMOS; CAVALCANTI, 2003).

Cabe ressaltar, que nem sempre há a disponibilidade de um aparelho sofisticado, por exemplo, de tomografia computadorizada, e neste caso pode-se utilizar a fotogrametria, sendo necessário uma máquina fotográfica ou filmadora digital (MORAES, 2015; MORAES; DIAS; MELANI, 2017). As imagens obtidas são inseridas no software para iniciar a reconstrução a partir dos pontos craniométricos. Para se obter sucesso usando esta técnica é preciso um equipamento de ótima qualidade de resolução, montado sobre um tripé, de forma que padronize altura e distância do crânio, a luz deve ser mantida na mesma intensidade e na mesma posição para que as fotografias possam ser transformadas em 3D (MORAES, 2015; MORAES; DIAS; MELANI, 2017).

O uso da fotografia na odontologia tem feito parte da rotina clínica cada vez mais frequente, com o intuito de registrar a situação inicial e após o tratamento do paciente, além de ter a função de documentação legal, para publicação de casos clínicos, elaboração de conteúdo educacional, e como meio auxiliar para demonstrar os procedimentos a outros pacientes (RAÍSSA ARAÚJO GONÇALVES, NATÉRCIA CARREIRA SORIANI; SILVA, 2018). A fotografia também é utilizada com finalidade pericial em casos de responsabilidade profissional ou “erros” odontológicos, sendo de extrema importância para a elaboração de laudos periciais, além da utilização da fotografia na identificação humana (RAÍSSA ARAÚJO GONÇALVES, NATÉRCIA CARREIRA SORIANI; SILVA, 2018). Ainda pode-se realizar a associação entre a fotografia *ante mortem* e os dados antropológicos e odontolegais, permitindo a identificação de indivíduos, pois essa associação de técnicas apresenta grande importância no processo de identificação humana (RAÍSSA ARAÚJO GONÇALVES, NATÉRCIA CARREIRA SORIANI; SILVA, 2018).

Entretanto não existe ainda estudos com embasamento científico tais como revisões sistemáticas se a fotogrametria pode ser usada como um método alternativo e fidedigno na determinação do dimorfismo sexual dos crânios, assim como a avaliação de outras estruturas anatômicas craniofaciais alternativas ao processo mastóide na determinação do dimorfismo sexual. Diante do exposto os objetivos das revisões sistemáticas foram: 1) estabelecer se a fotogrametria de crânios secos é confiável como método para estimar o sexo na identificação humana, e 2) e avaliar o grau de confiabilidade na determinação do dimorfismo sexual do processo mastóide comparando-o a outras estruturas dimórficas.

REVISÕES SISTEMÁTICAS

Revisão 1

A systematic review of photogrammetry as a reliable methodology in gender identification of human skull.

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A systematic review of photogrammetry as a reliable methodology in gender identification of human skull

Abstract

One of the most important parameters in the identification process in forensic Medicine and Dentistry is the determination of sex through the skull, based on morphological and metric dimorphism. Photogrammetry is an affordable option that allows the reconstruction of position, orientation, shape, and size, allowing the performance of quantitative and qualitative analyzes to identify the sex of the individual. However, there are few systematic reviews in the literature validating whether photogrammetry is a reliable methodology for sexual identification using human skulls. Therefore, the objective of the current systematic review was to validate whether photogrammetry of dry skulls is reliable as a method for calculating sex in human identification. This revision follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and was recorded in the Prospective International Systematic Reviews Registry (PROSPERO) (CRD420223 Systematic Registry) (CRD420223). The inclusion criteria for selecting the studies were based on the PICO question: "Is test photogrammetry reliable as a method for estimating sex in human identification?". A literature search for studies was performed in the databases MEDLINE Scopus, Web of Science, LILACS, and the Cochrane Library. The Kappa agreement presented an approval level of (k=0.93). This systematic review analyzed 11 *ex-vivo* studies published between 2001 and 2021. The risk of bias was considered low in 8 of the studies, and high in 3 studies. Based on this systematic review, it can be concluded that the photogrammetry method is viable and reliable in identifying sexual dimorphism.

Keywords: Skeletal sex determination; Sexual dimorphism; forensic anthropology; Photogrammetry.

INTRODUCTION

Human identification is one of the main areas of forensic Medicine and Dentistry, often presented as challenging and of superlative importance, with the main focus being to delimit the biological profile through the estimation of sex, age, ancestry, and stature [1–3]. In this sense, one of the most important parameters in the identification process is the determination of sex through the skull, based on morphological and metric dimorphism [1,2].

In several situations, the soft tissues are no longer present, due to the state and stage in which the corpse is found, which may include being charred, traumatized, in an advanced stage of decomposition, or even skeletonized [2,4–10]. Other factors that can be taken into account in the state in which bodies or fragments are found vary by: a) cause of death; b) environment in which the remains are maintained; c) climatic conditions of the place; and d) time taken to find the remains [11].

In such cases, forensic anthropology plays an important role in human identification [4,12]. One of the main characteristics considered in the anthropological analysis for identification is sex, however, generally, the skeletons found are not complete and the most reliable structures to analyze sexual dimorphism, the bones of the pelvis, may not be available [4,12,13].

When working with skulls, two types of analyses can be used to delimit the biological profile; qualitative or quantitative, in order to estimate the individual's sex, age, ancestry, and stature. Qualitative analysis is based on a visual morphological assessment of bone structures that present characteristics of sexual dimorphism, with subjective description, which may lead to inter- and intra-examiner errors. In addition, there is still racial miscegenation that can also be a complicating factor, as it is related to craniometric variability present in the same population [7,14]. Quantitative or morphometric analysis is performed using measurements, projections, and angles [2,15]. Although this is a more reliable analysis, the existing methods present the disadvantage of being outdated, since they use formulas developed specifically for a certain pattern of people, and have not received updates on evolutionary patterns for decades, despite ongoing racial miscegenation and environmental influences [2,4,7,10]. Therefore, there is a need to develop new methodologies, as well as to update the discriminant formulas described in the literature, to cover the largest number of temporally and geographically possible populations [2,10,15,16].

It is possible to proceed with human identification by directly analyzing the dry skull, through visual analysis, or using equipment such as a caliper. However, there are other methods and tools that can be used to perform these analyses, such as radiography, tomography, scanning, and skull photography, ensuring greater accuracy for the identification and standardization of methods [9].

Currently, access to digital photographs is part of everyday life, whether using professional cameras or even smartphones, which have been shown to produce good quality photographs. Photogrammetry is an affordable option that allows the reconstruction of position, orientation, shape, and size. In addition, this method does not require expensive hardware, and various options of free software are available that enable quantitative and qualitative analyses to identify the sex of an individual [9,10,15–21].

However, few systematic reviews in the literature have aimed to validate whether photogrammetry is a reliable methodology for sexual identification through human skulls. Therefore, the objective of this systematic review is to establish whether photogrammetry of dry skulls is reliable as a method for estimating sex in human identification.

MATERIAL AND METHODS

Protocol and Registration

This systematic review was registered in the Prospective Register of Systematic Reviews (PROSPERO - CRD42022342319), structured according to the Checklist of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [22], and in accordance with the Cochrane Handbook guidelines [23] and recently published systematic reviews [24,25].

Eligibility Criteria and PICO Question

Inclusion criteria for the selection of studies were assigned based on the PICO question, including studies that evaluated dry skulls (i) (P-population), identified by photogrammetry (ii) (I-intervention), compared or not with other imaging identification techniques (iii) (C-comparison), in order to analyze the confidence of the method for sex estimation in human identification (iv) (O -outcome). Studies that did not meet the inclusion criteria were excluded. In addition, studies that evaluated living and/or identified people, used recognition by facial analysis, by the skull overlay method with photography/and or antemortem radiography, age estimation, as well as identification by prostheses and restorative materials, bite marks, soft tissue, DNA, saliva, anomalies, and diseases were excluded. Non-human studies, literature reviews, and studies based on expert opinions were also excluded. Thus, a specific question was raised, based on population, intervention, comparison, and outcome criteria (PICO): "Is photogrammetry of dry skulls reliable as a method for estimating sex in human identification?"

Sources of Information and Search Strategy

Two independent reviewers (JCS and HBSS), guided by a specialized librarian, carried out a systematic search of the electronic databases PubMed/MEDLINE, Scopus, Embase, Web of Science, LILACS, and Cochrane Library, without language and publication time restrictions, until June 10, 2022. A specialized librarian guided the entire electronic search strategy, using MeSH terms and free terms properly adapted to the databases. Update alerts were created for the searches. In addition, the System for Information on Gray Literature in Europe (OpenGrey), Google Scholar, and a manual search were also used to identify potentially relevant additional studies. The search strategy adopted for searching the databases is reported in Appendix A.

Selection of Studies

In the initial stage of the study selection process, duplicate records obtained in the searches were removed using the application tool (EndNote Web; Thomson Reuters Inc., Philadelphia, PA, USA). Then, using EndNote software, two reviewers (JCS and HBSS) independently selected titles and abstracts that potentially met the inclusion criteria. Subsequently, the same reviewers individually read the full versions of the relevant articles and, in cases of disagreement, an open discussion with a third reviewer (GPN) was conducted to make the final decision. Agreement between reviewers regarding the study selection process was assessed by calculating the kappa correlation coefficient (IBM SPSS Statistics, v20.0; IBM Corp, Armonk, USA). When necessary, the corresponding authors were contacted to request information or clarifications directly via email, up to 3 times.

Data Extraction Process

Information on study characteristics (author, year, country), sample characteristics (collection origin, sample size, sample source), the intervention (intervention characteristics), methodological data (analyzed area, instrument of assessment), outcome-related information (percentage, mean/median values, and standard deviation of primary and secondary outcomes), and completion of the included studies was independently extracted by two reviewers (JCS and

HBSS) in Excel® spreadsheets (Microsoft Office 2017, Redmond , USA) and any disagreements were resolved by discussion and consensus of all authors (Table 1).

Quality Assessment and Risk of Bias

To analyze the validity and quality of each eligible study, the risk of bias was verified using a tool/qualifier [26], that was previously adopted in systematic reviews on craniofacial anthropometry [27,28]. Some modifications to the instrument were made in view of potential sources of bias unique to photogrammetric studies [29]. Thus, 16 items were included, evaluating four domains of the eligible studies: study design, photo-taking process, facial measurements, and adequacy of statistical analysis (Table 2).

The criteria used to assess the risk of bias were established as follows: a score of 0, 0.5, or 1 was assigned to each item indicating whether the study was free of bias, partially free of bias, and subject to bias for that item, respectively. In cases of inapplicable items, no scores were assigned. A score was calculated for each study by dividing the sum of item scores by the total number of applicable items. Studies with scores below 0.40 were considered as having a low risk of bias. Two trained and calibrated reviewers (GPN and JCS) evaluated the studies and a third reviewer (HBSS) resolved discrepancies.

RESULTS

Literature Search

The database search yielded 2712 studies: 1140 from PubMed/MEDLINE, 710 from Scopus, 84 from Web of Science, 774 from Embase, 2 from the Cochrane Library, and 2 from manual searches. After removal of duplicate studies, 1822 remained for evaluation of titles and abstracts. Of these, 17 articles were selected for full reading, with six articles excluded after applying the eligibility criteria (two for being studies with *in-vivo* photographs and four for analysis with a manual caliper). Thus, 11 studies [10,15,36,16,19,30–35], *ex-vivo*, were included. The inter-investigator Kappa agreement for articles included in all databases showed an acceptable level of agreement (k = 0.93) (Figure 1).

Risk of Bias

The classifications related to the risk of bias of the studies are detailed in Table 2. Of the 11 studies included in the review, 8 (72.7%) were classified as low risk of bias [10,15,16,19,31,33,36], and 3 studies (17.3%) as high risk of bias [30,32,34]. The scores of these studies ranged from 0.06 to 0.5.

Regarding the study design domain, 6 studies did not clearly report the inclusion criteria [19,30,32–35] and 3 studies did not inform the origin of the collection of the samples evaluated [15,33,34]. Considering the "photo taking" process, the majority of studies did not report the distance between the camera and the skull at the time of taking the photo [10,15,16,30–32,34] and did not clearly report the photographic parameters used [15,16,30–34,36]. As for the "face measurements" process, only 2 studies clearly provided written definitions of angular measurements. [10,19] and another 2 studies did not report the attempts made to ensure reliability [30,32]. Regarding the "statistical analysis" domain, 4 studies did not mention whether they considered confounding factors and did not provide the confidence interval, so the risk of bias could not be estimated. [19,30,32,34]. The other studies showed a low risk of bias for these items, since confounding factors were considered and the confidence interval was provided or could be estimated.

Description of Studies

All articles selected in this review used skull samples that are known and documented in their methodology. The studies were carried out in Cyprus [17], Australia [19,31,35], Canada [30], Thailand [36], Italy [33], Turkey [32], Korea [16], Czech Republic [10], and Greece[15].

The total number of skulls evaluated in the studies ranged from 3 to 572 skulls between males and females. The study by Thuanthong & Sudwan (2018) [36] reported the mean age of the skulls as between 66.02 ± 12.61 years. In the study carried out by Çelbis *et al*. (2001) [32], the authors reported that the skulls evaluated were from individuals over 20 years of age. Caple *et al*., (2018) [31], reported the mean age of the skulls evaluated by dividing them into groups (Black American female: 36 ± 15; Black American male: 39 ±12; White American female: 46 ± 12; White American male: 48 ± 11; Japanese male: 40 ± 12; Thai female: 55 ± 11; Thai male: 57 ± 16. The average ages for men and women reported in the study by Jung & Woo (2016) [16] were 57.29 and 62.63 respectively.

The exclusion criteria applied during the skull selection stage in all studies were that no important structure presented traumas, pathologies, or important malformations and total edentulous individuals that could impair the analyses. In addition, in the study by Caple *et al*. (2018) [31] skulls were also excluded when the styloid process overlapped the posterior border of the ascending ramus of the mandible, impairing the outline.

All studies highlighted the importance of methodological standardization for performing photogrammetry in forensic analysis to estimate sex from skulls. Photographs were taken with the skulls positioned in the frontal and left lateral norm, measurements were taken from the face to the base of the skull, that is, from left to right. For sex estimation, internal and external databases were used.

Nikita (2019) [34] and Nikita & Michopoulo (2017) [15] selected the following points as a reference for each analysis: glabella, mastoid process, and occipital protuberance. Caple *et al*. (2018) [31]: prosthion, infradental styloid, and mastoid. Thuanthong & Sudwan (2018) used the glabella and external acoustic meatus as reference with scale, and the points analyzed were: dacryon, ectoconchion, temporal frontomalar, nasion, nasio-spinal, prosthion, orbital, rhinion, zygion, asterion, bregma, glabella, porion, and mastoid. Berezowski *et al*. (2020) [30]: nasal, nasio-spinal, right and left alares, external acoustic meatus and posterior base of the mastoid process. Caple *et al*. (2017) [19]: skull in frontal and left lateral norm. Çelbis *et al.* (2001) [32]: glabellar region. Jung & Woo, (2016) [16]: mastoid process. Jurda & Urbanová (2016) [10]: skull, facial skeleton, supraorbital region and mastoid process. The Frankfurt plane was adopted as a reference for position standardization in all studies.

Craniometric analyses were performed using free or paid programs to estimate the sex of the skulls, with the exception of the study by Çelbis *et al.,* (2001) [32] which did not use software, only subjective analysis of the photographs. A variety of programs were used; Adobe Photoshop® (Adobe San José, California, USA) used in Cape *et al.* (2018) [31] and Caple *et al.* (2017) [19], Nikita (2019) [34] and Nikita & Michopoulo (2017) [15]. The study of Caple *et al.* (2017) [19]: also used a.tcl do psychomorphy, and Caple *et al*. (2018) [31]: used SkullProfiler. The study of Nikita (2019) [34] also used the program R Functions and the program Canny edge detector. Nonetheless, Thuanthong & Sudwan (2018) [36] used AutoCAD (version 2010, Autodesk), and Berezowski *et al*. (2020) [30]: Agisoft Photoscan and 3D Studio Max (3ds Max). Jung & Woo (2016) [16]: MakeFan. Jurda & Urbanová (2016) [10]: Photoscan V. 1. 3. 3, MicroScan – digitalizador MicroScribe G2X, GOM Inspect V. 8. 0, MeschLab V. 1. 3.3.

The accuracy percentage of the selected articles ranged from 84 to 87% for Nikita (2019) [34], 89% for Caple *et al*. (2018) [31], 93,1% in the global analysis for Thuanthong & Sudwan (2018) [36], 75% precision for Berezowski *et al*. (2020) [30], 84% male and 86% female accuracy for Çelbis *et al.* (2001) [32], and 87.3% mastoid process size factor of total shape variance and 12.7% sex factor for Jung & Woo (2016) [16]. The analysis of Jurda & Urbanová (2016) [10] attributed 82.5% of the skulls, for Nikita & Michopoulo (2017) [15], the best cross-validation results were obtained when the variables from the three frameworks were combined and ranged from 75.8 to 85.1% and 81.1 to 94.6% for men and women, respectively. The success rate was 86.3 to 94.1% for men and 83.9 to 93.5% for women when half of the sample was used for training and the remainder for prediction. The correct rating for the Cretan material based on the standards developed for the Athens sample was 80-90% for optimal combinations of discriminant variables. Caple *et al*. (2017) [19] did not present any percentages in their study.

DISCUSSION

Craniometry is the measurement of the bones of the skull by dividing them into planes that delimit their anatomical portions. From the measurements obtained, a comparison is made with a database, which can be performed manually or with the use of specific software [37–40].

Photography is used by forensic professionals from the moment they arrive at the crime scene, maintaining the original position of the body or remains before they are collected and taken to the laboratory. In the laboratory, all material is photographed again in order to document the initial condition, along with a scale so that its size is also recorded. After processing and cleaning the materials found, further photographs are taken of the skull, the dentition, and the skeletal characteristics used in the estimation of sex, age, ancestry, and stature[9].

It is also part of the standard operating protocol in the forensic field to x-ray all received remains, regardless of their condition [9]. The majority of laboratories have some type of X-ray machine, including digital equipment. The identification of individuals through radiographs has the disadvantage of being an exam that projects a three-dimensional object onto a two-dimensional surface, and with this, structures overlap, even when taken at different angles. As in photography, it is also necessary to use a scale to determine the real size of the structures [9,41].

Computed tomography is part of the advanced technology that has recently been incorporated into the forensic professional's arsenal of imaging techniques. Tomography allows the visualization of internal and external structures without being invasive or destructive and without overlapping images, unlike radiographs. Despite the benefits and potential of the method, the reality is that many laboratories do not have CT equipment due to the cost not only of the equipment, but also of the necessary software, in addition to the professional's experience to work with the data provided. Regarding the difficulties of using computed tomography, some reference points can be difficult to locate depending on the resolution of the tomography. Color and texture are also not preserved on tomography and, therefore, the location of sutures can only be discerned if the slice thickness is thin enough to capture the slight indentation in these regions [9,42–44].

Scanners differ from tomography in that they capture only external surfaces, making it impossible to capture internal images, or complex surfaces with large projections or deep crevices [9]. The majority of surface scanners also take pictures, thus allowing the color to match the object. Another advantage of scanners over tomography is that they are cheaper, portable, and have higher resolution [9]. In terms of forensic anthropology in the identification of the individual, this equipment has not been used, but because it is a 3D technology, it offers an opportunity to use new variables, such as surface areas, volume, contour, and surface relief, in the analysis of skeletal variation. There are two types of surface scanners; one is handheld, which can be moved around the object, and for the other, the object needs to be moved [9].

The study of Caple, Hons, Stephan, 2017 [19], used the Psychomorph, which makes it possible to produce computer graphics, so that the full range of size, shape, and texture information encoded in photographs, photorealistic, or morphotypes of the skull can be preserved. These methods have been available since the early 1990s [19]. The mean cranial shape was calculated for each photographic view, before each subject's color information was changed to the mean shape and combined to produce statistical averages [19]. These mathematically derived examples and their statistical exaggerations or extremes retain the high resolution details of the original photographic dataset, making them ideal standards of reference for cases and training [19].

Caple, Byrd, Stephan 2018[31], performed Elliptical Fourier analysis (EFA), using standardized photographs of the skull in lateral norm (left side). The authors report that the mid contours exhibit all the main features and also describe sexually dimorphic features. The main difference is the general size in relation to the contour of the female skull, which is smaller than the male skull, for all ancestral groups [31]. When the size information is removed, subtle differences in shape are still observed, in the midfacial region in females, which is relatively inferiorly displaced and paired with a larger cranial vault and less salient mandibular angle in relation to males, producing an accuracy of 73% of lateral skull contours. This can be used to successfully estimate ancestry and sex with similar accuracy to other methods and to lay the groundwork for future cross-validation tests [31]. In addition, the reliance on a single, easy-to-take photograph and an easy-to-use, open-source R script facilitates easy application and use in the field [31].

Nikita 2019 [34], carried out a study using lateral profile photography of the skull; the skull contour and profile of the glabella / frontal bone and occipital bone are automatically determined using the Canny edge detector [34]. Subsequently, sex estimation is achieved through just seven clicks on the digital cranial image: two clicks to rotate the image to the Frankfort plane, two clicks to define the frontal bone slope, two clicks to measure the mastoid process height, and one click on the nasion [34]. The R script subsequently calculates the discriminating variables and estimates the sex. The result presented in this study was 50% for women and 80% for men. The proposed R script provides functions that effectively capture the form of sexual dimorphism in cranial structures and produce correct classification results ranging from 84 to 87% for matched sexes [34]. Thus, the revised method considerably simplifies the original method for estimating sex in cranial morphology without losing accuracy. The greatest advantage of the R functions is their direct application, which reduces the time required for sex estimation per skull to approximately 1 minute after taking a digital photograph [34].

Nikita & Michopoulou, 2017[15], used the lateral photograph of the skull and after processing in Photoshop, or any other imaging software, obtained the contour of the glabella region, mastoid process, and external occipital protuberance [15]. The variables were calculated automatically in Excel VBA using the logistic regression models developed in this study. The sex estimation accuracy is improved when the discriminant variables from the three structures are combined. The correct classification rate ranges from 81.8 to 86.1% [15].

Thuanthong, Sudwan, 2019[36], analyzed digital photographs using AutoCAD[36]. In total, 15 parameters of the skull were analyzed using craniometry and 11 newly developed parameters. There was no significant difference between the AutoCAD measurement, from the digital photograph, and the digital pinch measurement, which was performed directly on the skull, and no significant difference between the measurements taken at the first and second time points, suggesting that the AutoCAD method is accurate enough to be used for sex determination [36].

Berezowsk, Rogers, Lucio 2021 [30], transformed photographs into 3D models using Agiosoft PhotoScan and imported the results into 3D Studio Max for digital evaluation [31]. Nasal opening, mastoid length, overall size and architecture, and measurement of the frontal bone projection through the left supraorbital crest were analyzed. This digital assessment method allows the quantification of each trace and minimizes instrument and user errors associated with the use of tweezers [30].

Çelbis, *et al*, 2001[32], using only photographs, evaluated the degree of smoothness-roughness of the supranasal region, and developed four prototypes ranging from 0 (smooth surface, female) to 3 (rough surface, male)[32]. The majority of prototypes 1 and 2 were classified as male, suggesting that males were primarily in prototypes 1 or above [32].

Jurda & Urbanová, 2016 [10], performed data collection in two ways: 3D surface scan and 3D coordinates with MicroScribe G2X digitizer [10]. In addition, 3D polygonal models were created using 2 techniques: photogrammetry using two sets of images taken while the skull was positioned in two positions, one taking into account the Frankfurt Plan and the other the basal view. A total of 40 images per cranial position were processed using the PhotoScan v application. 1. 0. 4 cranial position which were further edited with GOM Inspect v. 8.0 and MeshLab v 1. 3. 3. The 3D model sets were compared using mesh-mesh comparison in Fidentis Analyst v. 1. 3.2 The analysis demonstrated that the mesh-based approach is able to quantify within the craniofacial variation of the sample related to sex and ancestry. However, in relation to the accuracy of the sex classification, the results obtained were inferior to traditional methods and others aided by computer. The authors reported that these results are likely due to miscegenation in Brazil [10].

Jung & Woo, 2016 [16], evaluated the mastoid process through digital photographs, using MakeFan 7 software [16]. In this work, the findings suggest that mastoid size may be a more influential factor than shape in estimating the sex of skulls. Donato *et al.,* 2020 [33], evaluated the accuracy of photogrammetry compared with computed tomography [33]. The photographs were processed in Zephyr Lite software. For computed tomography, Slicer 3D software was used. The measurement of 3D meshes from photogrammetry and computed tomography was performed using ZBrush software. The results of the photogrammetric reconstruction measurements are useful for three-dimensional reconstruction and effective in lowering costs[33].

Omari *et al,* 2021 [35] used photographs taken with the camera of a Samsung Galaxy S8 cell phone, model SM-G950F Android version 9, 12 megapixel camera [35] and Angiosoft Metashape 1.5.5 Professional Edition software. Skulls were also scanned using CT scanning. The DICOM files from the CT scan were visualized using Radi Ant TM DICOM v. 5. 0. 2. This study demonstrated that photogrammetry can give results as accurate as those obtained from physical tests and computed tomography measurements, being a reliable and reproducible method. In addition, the authors demonstrated that it is not necessary to use a professional camera [35].

With the data obtained from this review, it is concluded that despite technological advances, some centers do not have tomography devices, due to their high cost, so the use of photography is an extremely important method, that is easy to access, as well as low cost. This method presents a high degree of reliability in the identification of sexual dimorphism. However, to date, no studies have provided a standardized method, which is capable of reproducing without errors of execution on behalf of the professional, and that provides updated averages of comparisons between the races, mainly for a population that presents high miscegenation. In this way, further studies and protocols are needed for the standardization and identification of sexual dimorphism, age, race, and height in human identification from skulls.

CONCLUSION

Even with the limitations of the study, photogrammetry is a viable and reliable method for identifying sexual dimorphism in skulls. However, more robust and standardized trials are needed to confirm the results, with less heterogeneity and a higher quality of evidence.

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Appendix A

Search Strategy

#1

Skull OR Skulls OR Cranium OR Calvaria OR Calvarium OR Cephalometry OR Craniometry OR Anthropometry

#2

Photogrammetry OR Photogrammetries OR Stereophotogrammetry OR Stereophotogrammetries OR photography OR Photographies OR (forensic anthropology) OR (Anthropology, Forensic) OR (Human Identification) OR (Human Identifications) OR (Identification, Human) OR (Identifications, Human)

#3

(Sex Determination by Skeleton) OR (sex characteristics) OR (Sex Determination by Skeleton / methods)

#1 AND #2 AND #3

Table 1 – General data on the selected studies.

Author / Year	Country	Origin of skulls	Sample size	Sample source	Area analyzed	Intervention characteristics	Assessment instrument	Results	Conclusions
ÇELBIS *et al.*, 2001 [32]	Turkey	Caucasoid	90	Council of Forensic Medicine, Istanbul, Turkey.	Glabellar region	Photographs of the glabellar region	Subjective analysis - with a score from 0 to 3	The results indicated that none of the men were assigned to Prototype 0 and, conversely, none of the women were classified as Prototype 3.	This study shows that there is an identifiable sexual dimorphism in the supranasal region, but its origin is not well known. This is expected to result from the muscles of both facial expression and masticatory function.
JUNG & WOO, 2016[16]	Korea	white American	200	Collection of skeletons donated by William M Bass of the University of Tennessee	Mastoid process	Photographs of the right mastoid process and software use	Photography: Nikon AF-S MICRO NIKKOR 105mm lens MakeFan: 27 landmarks Procrustes overlay – organize all coordinate data	The size and shape of the mastoid were statistically significant indicators of sex, while the size factor explained 87.3% of the total variance in the shape variables. However, females had a relatively wider and shorter mastoid shape than males, regardless of size, reflecting 12.7% of the total variance in shape variables.	In this study, mastoid size and shape were statistically significant sex indicators in classifying both sexes with modern white American samples. However, mastoid size may be a more significant factor in classifying each sex than shape, considering the relationship between mastoid size and shape.
JURDA & URBANOVÁ,2016[10]	Czech Republic	Afro-Brazilian Europeans-Brazilians Mestizos - Brazilians	80	1- Museum of Human Anatomy of the University of São Paulo 2- Collection housed in the Paulista School of	Skull, facial skeleton, supraorbital region, mastoid process	photography and software scanner and software	Nikon D7000, Nikon AF-S micro 60mm lens Photoscan v 1.0.4 MicroScan –	The highest levels of accuracy for sex determination were obtained for meshes representing the facial skeleton and the supraorbital	The highest levels of accuracy for sex determination were obtained for meshes representing the facial skeleton and the supraorbital region.

				Medicine of the Federal University of São Paulo			MicroScribe G2X digitizer GOM Inspect v8.0 MeshLab v.1.3.3	region.	
CAPLE *et al.*, 2017[19]	Australia	South African blacks and whites American blacks and whites Japanese	108 186 69	1 - Pretoria Bone Collection – Pretoria Anatomy Department 2 - Cleveland Museum of Natural History 3- Department of Anatomy of the University of China	Skull in frontal and left side norm	Front and left side photography Resized and analyzed in software	Photography: Canon 6D DSLR – Canon 100mm lens Resized in Adobe Photoshop CS6 Outlined in the a.tcl version of Psychomorphy	Psychomorph provided photorealistic skull averages Sex differentiation skulls with increased overall size and robustness for men	It is possible to generate graphical specimens based on statistics of skull morphology by sex and ancestry
NIKITA & MICHOPOULOU, 2018[15]	Greece	--------	185	1- Athens Collection of the National Kapodistrian University of Athens 2- Crete Collection	Profile of the glabella, mastoid process, external occipital protuberance	Left side photography and software	Photography Adobe Photoshop-extract the outline of structures Calculation of variables – automatically in EXCEL VBA Macro	The cross-validation results of the three frameworks were combined and ranged from 75.8 to 85.1% and 81.1 to 94.6% for men and women, respectively. The success rate is 86.3 to 94.1% for men and 83.9 to 93.5% for women when half of the sample is used for training and the rest for prediction. The correct rating for the Cretan material based on	It is a more accurate method than existing alternative approaches based on qualitative recording schemes or craniometry. Although the proposed method takes longer, its advantage lies in the fact that it overcomes the subjectivity that characterizes any qualitative approach. It focuses on anatomical structures that present relatively high levels of sexual dimorphism and are often well preserved, not requiring specialized equipment.

								the standards developed for the Athens sample was 80-90% for optimal combinations of discriminant variables.	
CAPLE *et al.*, 2018[18]	Australia	Black American Japanese Thai White American	196 59 86 231	1- Hamann-Todd Human Osteological Collection, 2 - Skeletal Collection Donated by WM Bass, 3 -Robert J. Terry's Anatomical Skeletal Collection, 4 - Khon Kaen Osteological Collection, 5 - Chiba Bones Collection	Contours acquired from standardized photographs of the skull in norma lateralis (left side).	Using Elliptic Fourier Analysis (EFA), ancestry and sex were estimated using contours acquired from standardized photographs.	Photography Adobe Photoshop SkullProfiler Partial generalized Procrustes analysis Fourier Elliptic Analysis	Ancestry and sex were correctly classified 73% of the time when all seven reference samples were used. When only Black and White Americans were retained in the sex-grouped reference sample, they were correctly classified 94% of the time.	The lateral contours of the skull can be used to successfully estimate ancestry and sex with similar accuracy to other methods and lay the groundwork for future cross-validation tests. In addition, the reliance on a single, easy-to-take photograph and an easy-to-use open source R script makes application and use in the field easy. The protocol is freely available from CRANIOFACIALidentification.com as the SkullProfiler script.
NIKITA E.,2019[17]	Chipre	-------	185	1- Athens Collection of the National Kapodistrian University of Athens	Profile of the glabella, mastoid process, external occipital protuberance	Left side photography and software	Photography Adobe Photoshop cranial contour - Canny edge	proposed R script provides functions that effectively capture the shape of sexually dimorphic cranial	The revised method considerably simplifies the original method of estimating sex based on cranial morphology, without losing accuracy. The biggest advantage of the R functions is their straightforward application, which

				2- Crete Collection			detector and discriminant variables script R	structures and produce correct classification results ranging from 84 to 87% for clustered sexes	reduces the time required for sex estimation per skull to about 1 minute after taking a digital photograph.
THUANTHONG & SUDWAN P.,2019[36]	Thailand		160	Collection housed in the Department of Anatomy, Faculty of Medicine, University of Chiang Mai, Thailand.	Orbital height (OrH), orbital width (D-Ec), nasal bone length (NL), external nasal opening height (ENOH), maxillary alveolar process height (APMH), bizygomatic width (Zy-Zy), area orbital (OrA), orbital perimeter (OrP), external nasal opening area (ENOA), external nasal opening perimeter (ENOP), mastoid triangle area (MTA), zygomatic arch area (ZaA), zygomatic arch	Front and left side view software digital caliper	Canon EOS 1000D AutoCAD digital caliper	Men are significantly larger than women in all parameters except the nasospinale-prosthion measure. There were no significant differences in the intra-observer error test and between AutoCAD and the digital caliper Measurements. Logistic regression analysis yielded a sex classification accuracy rate of 92.9% in men, 93.4% in women, and 93.1% overall accuracy for AutoCAD software. When using digital calipers, there was an accuracy rate of 89.3% in men and 94.7% in women, and 91.9% for overall accuracy.	Sex determination of skulls from northern Thailand using AutoCAD and conventional caliper methods examined in the present study shows high accuracy for both methods and is suggested for use to predict sex from skeletal remains.

					perimeter (ZaP), glabella-bregma area (GBA) and glabella-bregma perimeter (GBP) were measured.				
DONATO *et al.*/2020[33]	Italy	-----	8	19th century Italian Tenchini anatomical collection	3D skull volume	Front, side, back and top photography Computed tomography software	Nikon Coolpix P7100 Camera Software: Zephyr – assess accuracy level Computed tomography 3D Slicer software – to process the DICOM file Z Brush – digital sculpting tool for creating high resolution models.	The Bland–Altman plot showed homogeneity of results depending on the cut, as the difference variable was normal. On the other hand, the mean difference (1.28 mm) was significantly different from 0 ($p < 0.01$), indicating that photogrammetry slightly overestimated the measurements in relation to CT.	CT will always be irreplaceable for visualizing structures within the unit of interest; however, photogrammetry represents an excellent tool for the study and analysis of the external surface.
BEREZOWSKI *et al*, 2021[30]	Canada	Europeans	91	Skeletal Collection Donated by William M. Bass – University of Tennessee Knoxville Center for Forensic Anthropology	Nasal opening, Mastoid length, Overall size and architecture of the skull, Supraorbital ridges	Front and side photography The analyzes were performed in the software	Canon Rebel T3i DSLR Camera Software: Agisoft PhotoScan 3D Studio Max	Training sample 90% accuracy Sample test 75% accuracy.	The digital evaluation method allows a combined analysis of size and shape traits. Minimizes instrument and professional errors. Allows quantification of traits, and refinement. Avoids having to exhume the body, and excessive handling.
OMARI *et al.* /2021[35]	Australia	Caucasian	3	Bone Clone	Entire skull	Photograph from	Camera:	Statistical tests	This study demonstrated that

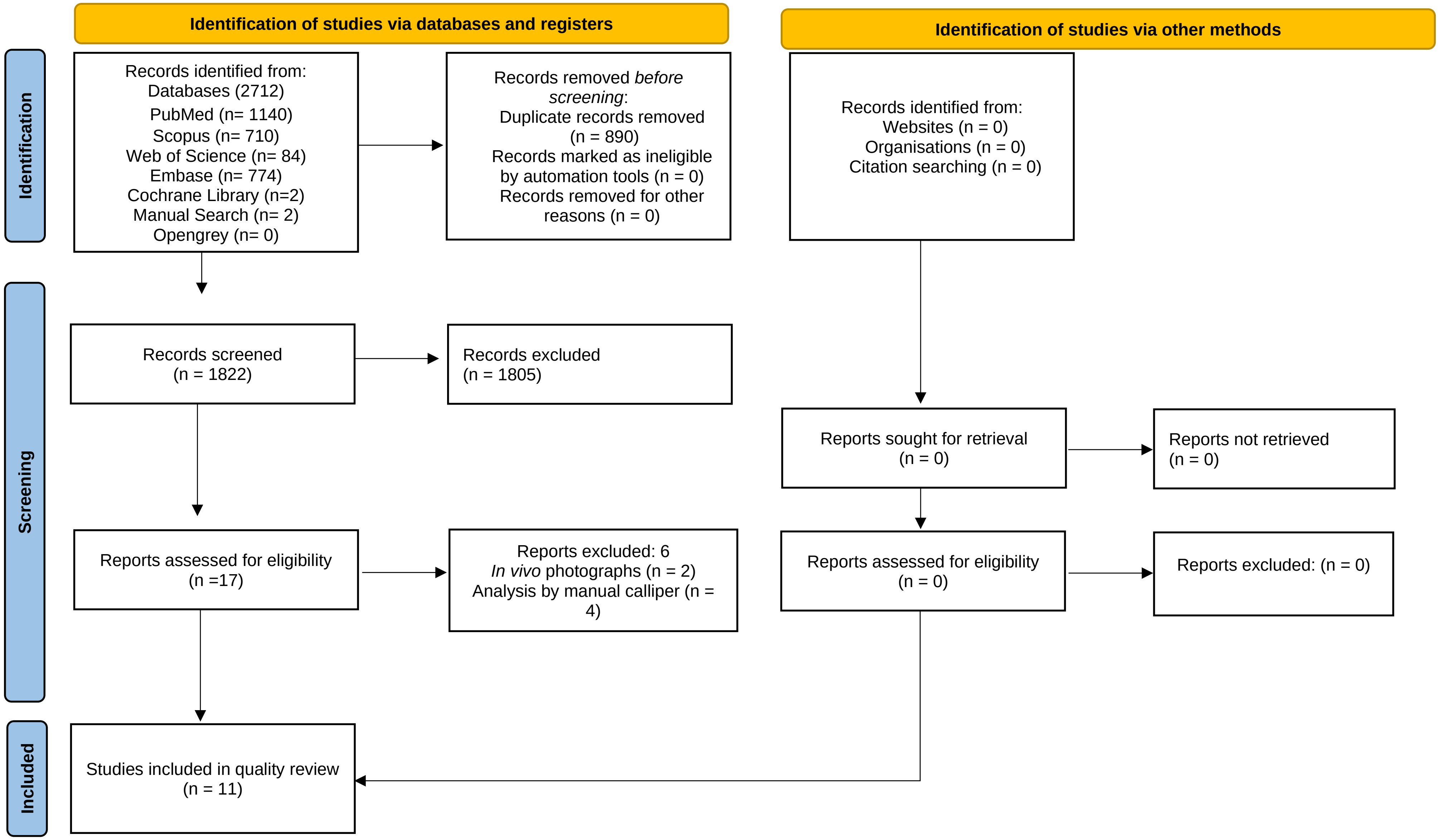
		African American Asian				top to bottom, anterior part (frontal, lateral and occipital), at the level of the mandible, base of the skull. skull tomography software	Samsung Galaxy S8 model SM – G950F Android version 9 12 megapixels. Sliding digital clamp: Vernier Craftringht 0-150 mm. External digital spreader clamp: Moore & Wright 0-150 mm/6”. Tomography: Canon Aquilion Lightning 80 CT Scanner. Software: Agiosoft Metashape RadiAnt DICOM Vierwer.	have shown that photogrammetry is a reliable and accurate alternative.	photogrammetry can provide results as accurate as those obtained from physical and tomographic measurements and that it is a reliable and repeatable method. Any camera (including a phone camera) can be used as long as it has high resolution

Table 2. Risk of bias of included studies.

Criterion	**Çelbis *et al.*, 2001 [33]**	**Jung & Woo, 2016 [16]**	**Jurda & Urbanová, 2016 [10]**	**Caple *et al.*, 2017 [19]**	**Nikita & Michopoulou, 2017 [14]**	**Caple *et al.*, 2018 [18]**	**Nikita, 2019 [17]**	**Thuanthon & Sudwan, 2019 [30]**	**Berezowski *et al.*, 2020 [31]**	**Donato *et al.*, 2020 [34]**	**Omari *et al.*, 2021 [36]**
Ⅰ. Study design											
A. Objective clearly formulated	0	0	0	0	0	0	0	0	0	0	0
B. Sample size for each gender ≥ 30 subjects	0	0	0	0	0	0	0	0	0	1	1
C. Sampling method clearly reported	0.5	0	0	0	0	0	0	0.5	0	0	0
D. Inclusion criteria clearly reported	0.5	0	0	0.5	0	0	1	0	0.5	1	1
E. Origin of samples clearly reported	0	0	0	0	1	0	1	0	0	1	0
Ⅱ. Photo taking process											
F. Subjects' Skull position clearly reported	0.5	0	0	0	0	0.5	0	0.5	0.5	0	0.5
G. Subjects' Skull area/region clearly reported	0	0	0	0	0	0	0	0	0	0	0.5
H. Camera-subject distance clearly reported	1	1	1	0	1	1	1	0	1	0	0
I. Photographic parameters clearly reported	1	0.5	0	0	1	1	1	0.5	1	0.5	0
Ⅲ. Facial measurements											
J. Definitions of landmarks clearly described	0.5	0	0	0	0	0.5	0	0	0	0	0
K. Definitions of linear measurements clearly described	0	0.5	0	0	0.5	0.5	0	0	0	0.5	0.5
L. Definitions of angular measurements clearly described	1	0.5	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
M. Attempts to ensure and quantify reliability	1	0	0	0	0	0	0	0	1	0	0
Ⅳ. Statistical analysis											
N. Statistical analysis appropriate for data	0	0	0	1	0	0	1	0	1	0	0
O. Confounders accounted for in analysis	1	0	0	1	0	0	1	0	1	1	0
P. Confidence intervals provided	1	0	0	1	0	0	1	0	1	0	0
Percentage score	0.5	0.16	0.06	0.22	0.25	0.25	0.47	0.13	0.47	0.34	0.25
Risk of bias level	H	L	L	L	L	L	H	L	H	L	L

L: Low risk of bias; H: High risk of bias

Figure 1 - PRISMA flow chart— flow diagram showing the entire search process



Revisão 2

Cranial anatomical structures with high sexual dimorphism in metric and morphological evaluation: A systematic review

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Cranial anatomical structures with high sexual dimorphism in metric and morphological evaluation: A systematic review

Abstract

The mastoid process has attracted the attention of several researchers due to its protected position at the base of the skull and the fact that it is relatively compact, in addition to being highly resistant and dimorphic, considered as a gold standard anatomical structure in the determination of the sexual dimorphism of skulls. However, intrinsic and extrinsic factors may influence this anatomical structure over time, providing contradictory and ambiguous data. Therefore, other anatomical structures need to be evaluated concurrently with the mastoid process for better accuracy and reliability of skull sexual dimorphism data. Thus, the objective of this systematic review was to evaluate the degree of reliability of the mastoid process to determine sexual dimorphism compared to other dimorphic structures, since there are still no systematic reviews on the subject in the literature. This review follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and was recorded in the Prospective International Systematic Reviews Registry (PROSPERO) (CRD 42023395167 Systematic Registry) (CRD420223). The inclusion criteria for selecting the studies were based on the PICO question: “Are skull anatomical structures reliable as alternatives to determine sexual dimorphism compared to the mastoid process?”. A literature search for studies was performed in the MEDLINE Scopus, Web of Science, LILACS, and Cochrane Library databases. The Kappa agreement presented an approval level of k = 0.93. This systematic review analyzed 12 *ex-vivo* studies published between 2008 and 2020. The risk of bias was considered low in 8 of the studies, and high in 4 studies. Based on the findings, it can be concluded that even with the limitations of this systematic review, quantitative and qualitative analyses are essential in sexual identification of human skulls, and different anatomical structures can be used as references in addition to the mastoid process, with high reliability and precision, among them; glabella, frontal profile, superciliary arch, bizygomatic width, maximum cranial length, and nasal height.

Keywords: Forensic anthropology; Human identification; Mastoid; Sex characteristics.

Introduction

Identification of human remains is a fundamental task in both forensic medicine and forensic anthropology [1–6]. In the absence of soft tissues, the skeletal remains are analyzed with the purpose of building the biological profile of the individual, to obtain information about ancestry, sex, height, age at death, and history of diseases, among other information that may contribute to identification [1–4,7–10]. Sex determination is one of the first analyses carried out, since age and height are directly related to the individual's sex [3].

The skull is the most dimorphic and sexual structure of the human skeleton after the pelvis, providing up to 92% reliability [11]. The mastoid process has attracted the attention of several researchers due to its relatively compact and protected position at the base of the skull, in addition to its being highly resistant and dimorphic [3,5]. The mastoid process usually remains intact and can be found intact even in very old skulls [2,4,12]. This anatomical structure is more robust in males than in females. In forensic medicine, these sex differences regarding the shape and size of the mastoid process are investigated using traditional morphological and metric methods [2–5,7–9,13].

Furthermore, the mastoid process and its surrounding region represent one of the most sexually dimorphic parts of the human skull and are often included in data collection protocols and methods of sex identification in cadavers [5,14]. In addition, it is an anatomical structure that can be visually evaluated for its massiveness and volume [2], either metrically in relation to its length/height, which is normally measured as the vertical projection of the mastoid process, below and perpendicular to the Frankfurt horizontal plane[5].

In the literature, when searching for sexual dimorphism through the skull, from the last century to the present day, many articles are found that use the mastoid process as an analysis structure, due to its dysmorphic characteristics, and also to its location and robustness. It can be analyzed even in fragmented and burned skulls, becoming a gold standard structure in relation to sexual dimorphism [2,5].

However, structures can also be found with anatomical variations that present contradictory or ambiguous characteristics in relation to sexual dimorphism [15]. There is evidence that decreased muscle action, severe malnutrition, and wasting can decrease the accuracy of these methods [13]. This suggests that intrinsic and extrinsic factors can influence different cranial features, and therefore more than one structure should be evaluated for better data accuracy and reliability [15]. Of the five anatomical structures most commonly used in the visual method to determine sexual dimorphism; the nuchal crest, mastoid process, and glabella are affected by biomechanical forces because they are sites of muscle attachments for functions such as movement of the eyebrows, head, and neck [16].

In addition to the mastoid process, the glabella, nuchal crest, and orbital margin are also relevant structures in sexual dimorphism [6,15,17–19]. Various measurements can be taken from the skull. However, many parameters are not valid for determining sex in practice, since the skull has approximately 5000 cranial measurements, including structures with low or zero sexual dimorphism [20]. For a method to be effective, it needs to present certain characteristics such as: fast analysis, without relying on a high level of experience to obtain reliable results, and analysis of the most dimorphic structures [21].

Therefore, the objective of this systematic review was to evaluate the degree of reliability in determining the sexual dimorphism of the mastoid process compared to other dysmorphic structures, bearing in mind the importance of the subject and the scarcity of systematic reviews about this topic in the literature.

1. MATERIAL AND METHODS

Protocol and Registration

The following systematic review was registered in the Prospective International Registry of Systematic Reviews—PROSPERO 2019 (http://www.crd.york.ac.uk) under number CRD 42023395167, and developed based on the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) protocol for systematic reviews (http://www.prisma-statement.org) [22].

Research Question and Eligibility Criteria

Studies were selected based on the PICO question, including studies that evaluated dried skulls (P- population) identified by anatomical structures of the skull (I-intervention) or through the mastoid process (C-comparison) to observe the confidence and precision/accuracy of these structures in the human identification process (O-outcome). We aimed to answer the focus question: Are skull anatomical structures reliable as alternatives to determine sexual dimorphism compared to the mastoid process?

Similarly, the eligibility criteria that guided the selection process of the studies included were based on the PICO structure. The inclusion criteria comprised studies performed on dry skulls, which compare the mastoid process and other craniofacial anatomical structures, regarding the reliability and precision/accuracy of these anatomical structures in sexual dimorphism. The exclusion criteria applied in the full-text analysis were studies including living or identified persons, age estimation, prostheses and restorative materials, bite marks, soft tissue, DNA, saliva, anomalies, and illnesses. Systematic reviews and meta-analysis, descriptive studies, review articles, opinion articles, technical articles, guidelines, studies on animals, and *in vitro* experiments were excluded. No restrictions were placed on the publication date or language used.

Search Strategy

Five electronic databases - PubMed, Scopus, Web of Science, Embase, and the Cochrane Library, and a gray literature source - OpenGrey were accessed to perform the search strategy from October 2022 to March 2023. The MeSH terms used were “Skull” “Cranium”, “Calvaria”, “Calvarium”, “Craniometry”, “Anthropometry”, “(Sex Determination by Skeleton)”, “(sex characteristics)”, “(forensic anthropology)”, “(Human Identification)”, and (Identifications, Human)”. Both MeSH and entry terms were correctly adapted according to the syntax rules for each database and the gray literature, using Boolean operators (AND, OR) to combine terms. To find additional citations, a manual search was performed in the references of the included studies. A search alert was activated in each database to receive notifications when new articles matched our search query. The search strategy adopted for searching the articles in the databases is reported in Appendix A.

Selection Process and Screening of Articles

The retrieved documents were exported and organized in reference management software (EndNote®, version X7, Thomson Reuters, Philadelphia, USA) and the identified duplicates were manually and automatically excluded. Two reviewers (JCS and HBSS) read the titles and abstracts independently to determine whether the articles met the inclusion and exclusion criteria according to the PICO strategy. Selected articles were read in full to confirm eligibility. If the two reviewers were unsure about the inclusion/exclusion of any article, the issue was solved through a consensus meeting with a third reviewer (GPN). Reasons for the exclusion of articles after full-text examination were registered. Articles published in languages that the authors of this study did not know were translated using the GoogleTM Translate Tool at https://translate.google.com, accessed on 02 February 2023. Agreement between reviewers on the study selection process was assessed by calculating the kappa correlation coefficient

(IBM SPSS Statistics, v20.0; IBM Corp, Armonk, USA). The kappa inter-investigator agreement for articles selected from databases (K=0.93), demonstrated a high level of agreement.

Data Extraction and Quality Assessment

To summarize the main findings, the following data were extracted from the included articles: authors and year, country, sample size, area analyzed, intervention characteristics, evaluation method/assessment instrument, results, and conclusion (Table 1). Authors were contacted by email when data were missing or if clarifications were required.

The quality assessment of all eligible articles was performed to investigate the internal validity of the study methods, interpretation of the results, and applicability of the findings. To analyze the validity and quality of each eligible study, the risk of bias was checked based on a tool/qualifier (Gordon *et al*., 2009) [23] that has been adopted in systematic reviews on craniofacial anthropometry [24,25]. Some instrument modifications were made in view of potential sources of bias exclusive to studies with sexual dimorphism. Thus, 16 items covering four domains of the included studies were evaluated: study design, instrument-taking process, area/region of measurements, and statistical analysis (Table 2).

The criteria adopted for analysis of methodological quality and risk of bias were assigned as follows: a score of 0, 0.5, or 1 was established for each item, indicating free of bias, partially free of bias, and subject to bias, respectively. In cases of inapplicable items, scores were not assigned. A score was calculated for each study by dividing the sum of item scores by the total number of applicable items. Studies with scores below 0.40 were considered as low risk of bias. Two trained and calibrated reviewers (GPN and JCS) evaluated the studies and a third reviewer (HBSS) resolved discrepancies.

RESULTS

Literary Search

The database search retrieved 2788 studies, including 1443 from PubMed/MEDLINE, 1110 from Scopus, 155 from Web of Science, 75 from Embase, and 5 from the Cochrane Library. After removing duplicate studies, 1800 remained for evaluation of titles and abstracts. Of these, 16 articles were selected for full reading, from which a total of four articles excluded for not meeting the eligibility criteria and/or for lack of information/data (Figure 1). Thus, 12 *ex-vivo* randomized studies [6,13,15–20,26–29] were included in the current systematic review.

Description Of Studies

All articles selected in this review used known and documented skull samples in their methodology, with the exception of the study by Banic *et al.* (2016) [6] who performed DNA testing on all skulls to determine sex in order to confirm the degree of reliability of their research results. The studies were carried out in Greece [27], Brazil [30], USA [15,16,26,28], Romania [19], South Africa [18], Thailand [20], Bosnia and Herzegovina [17], Croatia [6], and Chile [29].

The number of skulls evaluated in the studies ranged from 40 to 499 skulls between males and females. The study by Soficaru *et al*. (2014) [19] reported the mean age of the skulls as ± 49 years; the study by Krüger *et al.* (2015) [18] as ± 59 years; and the study by Kranioti *et al*. (2008) [27] as ± 66 years; the study by Fatah *et al*. (2014) [28] reported a mean age of male skulls of ± 64 years and of female skulls of ± 66 years; and finally the study by Mahakkanukrauh *et al*. (2015) [20] reported a mean age of male skulls of ± 65 years and of female skulls of ± 66 years. The studies by Banic *et al.* (2016) [6], Ajanovic *et al.* (2016) [17], Garvin *et al.* (2014) [15], Alves *et al.* (2020) [29], Casado (2017) [26], Godde *et al*. (2018)[16], and Suazo *et al*. (2009) [30] did not report the mean age of the analyzed skulls. The exclusion criteria applied during the skull selection stage in all studies were that no important structure presented trauma, pathologies, or major malformations and no total edentulous skulls that could jeopardize the analyses.

Qualitative Analyses

The studies by Garvin *et al.* (2014) [15]; Krüger *et al*. (2015) [18]; Soficaru *et al.* (2014) [19]; and Banic *et al.* (2016) [6] performed the qualitative analysis according to Walker [21], using the following structures: mastoid process, glabella, supraorbital margin, nuchal crest, and mental eminence. The study by Godde *et al*. (2018) [16] used the same qualitative analysis adopted by the previous authors, however without analysis of the mental eminence.

In the study by Alves *et al.* (2020) [29], the following anatomical structures were analyzed: glabella, nuchal plane, frontal and parietal eminence, frontal profile, superciliary arch, orbit shape, zygomatic process of the temporal bone, external occipital protuberance, mastoid process, and zygomatic bone; following the classification by Walrath *et al*. (2004) [31], with modifications.

The study by Suazo *et al*. (2009) [30] evaluated sixteen classic anatomical structures of sexual dimorphism, as described by Krogman and Krogman & Iscan [32]; the size and architecture of the skull, shape of the forehead, frontal eminences, superciliary arches, orbital shape, piriform opening, nasal bone, zygomatic bone, zygomatic arch, parietal eminences, mastoid process, occipital bone, occipital condyles, shape of the palate, general appearance of the jaw, and shape of the chin.

The study by Ajanovic *et al.* (2016) [17] analyzed eleven anatomical structures: the prominence of the parietal tubercle; frontal tubercle prominence; prominence of the superciliary arch; prominence of the glabella; appearance of the supraorbital margin; orbit appearance;

width of the root of the nose; prominence of the mastoid process; contours of muscle insertions; tooth size; and face shape.

In the study by Alves *et al.* (2020) [29], the frontal profile was the variable that presented the highest reliability for sex diagnosis, followed by the superciliary arch, with a correct sexual classification of 75.8% and a higher percentage of male skulls correctly diagnosed compared to female skulls. In the study by Suazo *et al*. (2009) [30], it was observed that the frontal profile presented an accuracy of 80.14%, with a higher percentage of correct diagnoses for women (84.94%) than men (77.65%); and accuracy of 78.79% for sex diagnosis using the superciliary arch, with a higher percentage of correct diagnosis for male skulls (79.21%) than female (77.89%). However, Suazo *et al*. (2009) [30] observed that the mastoid process was the most accurate anatomical structure (84.75%). In the study by Alves *et al.* (2020) [29], correct sexual identification using the mastoid process was 63.8%.

The results reported by Garvin *et al.* (2014) [15] and Krüger *et al*. (2015) [18] differ from previous studies by showing that the glabella and mastoid process are the most reliable anatomical structures for determining sex differences. These authors reported 80% accuracy (94% in men and 67% in women) in sex determination using the glabella and mastoid process. However, in the study by Krüger *et al*. (2015) [18], the highest accuracy was found using 3 structures: glabella, mastoid process, and chin (84% combined, 92% in men, and 76% in women).

The study by Godde *et al*. (2018) [16] obtained the following results regarding the analyzed structures; the glabella was the most reliable with 78%, followed by the mastoid process with 52%, supraorbital margin with 51%, and the least reliable structure was the nuchal crest, with 26%. On the other hand, in the study by Soficaru *et al.* (2014) [19], the first and second authors obtained intraobserver scores of 65% and 78% for the orbital, 73% and 74% for the mental eminence, 71% and 76% for the mastoid process, 84% and 85% for the nuchal crest, and 84% and 87% for the glabella, respectively.

Ajanovic *et al.* (2016) [17] analyzed ten skull structures: frontal tubercle prominence; prominence of the superciliary arch; glabella prominence; appearance of supraorbital margin; orbit appearance; width of the root of the nose; prominence of the mastoid process; contours of muscle insertions; teeth size; and face shape. All observed structures showed a statistically significant effect on sex determination, while the prominences of the superciliary arch and the glabella presented 90% accuracy, followed by the prominence of muscle insertions with 82% accuracy, and the prominence of the mastoid process with 75% accuracy. When using multivariate binary logistic regression, it was observed that the anatomical structures of the superciliary arch, glabella, and mastoid process size were more reliable in sex determination.

However, the study by Banic *et al.* (2016) [6] showed the opposite result in relation to other studies, with the mastoid process being the least reliable structure, while the nuchal line and orbital shape were the most reliable anatomical structures. Differently from the other studies, the percentage of reliability of each structure was not informed in the article.

Quantitative Analyses

The studies by Mahakkanukrauh *et al*. (2015) [20] and Kranioti *et al*. (2008) [27] performed the measurements with sliding calipers or spacers; the study by Casado (2017)[26] used a coordinate compass that resembles the traditional sliding compass, but has an intermediate arm that descends to capture the three-dimensional nature of an anatomical feature. The study by Fatah *et al*. (2014) [28] differs from the previous studies in that the skulls were packed in padded foam boxes and computed tomography was performed using cubic voxels of 0.625 x 0.625 x 0.625 mm. The measurements were performed after the surface models had been generated.

The study by Casado (2017) [26] analyzed six structures, three muscle insertion sites: mastoid process, external occipital protuberance, and nuchal area; and three cranial structures that are sexually dimorphic: glabella, supraorbital ridge, and frontal salience. Overall, 72.2% of the skulls were classified correctly, a figure similar to results from traditional methods and as reliable as the established visual sex estimation techniques. Men were classified correctly in 69.6% of cases and women in 74.7%; and the variable with the greatest influence in this study was the external projection of the right and left mastoid process.

The study by Kranioti *et al*. (2008) [27] analyzed sixteen dimensions taken from the neural and facial portions of the skull. These dimensions were: maximum cranial length, basion-nasion length, maximum cranial vault width, maximum frontal width, minimum frontal width, bizygomatic width, foramen magnum length, foramen magnum width, basium-bregma height, basion–prostium length, height of nasion-prostium, height of mastoid process, bio-orbital width, interorbital width, nose width, and nose height. Bizygomatic width was the most discriminating single dimension and provided an accuracy rate of 82% on average. Using a step-by-step method involving five dimensions (bizygomatic width, cranial length, nasion-prostium, mastoid height, and nasal width), the accuracy increased to 88.2%.

The study by Mahakkanukrauh *et al*. (2015) [20] performed twenty-five measurements: maximum skull length; maximum cranial width; bizygomatic width; basion-bregma height; skull base length; binaural width; minimum front width; upper face width; nasal height; nasal width; orbital width; orbital height; bio-orbital width; interorbital width; front overhang; parietal protrusion; occipital protrusion; length of the foramen magnum; width of the foramen magnum; length of the right mastoid process; length of the left mastoid process; maximum front width; length of the basion-nasospinal; biasterionic width; and minimum width of the nasal bone. Measurements showed that all structures were statistically significantly different between men and women, except for the minimum width of the nasal bone. The 12 most sexually dimorphic variables were used in the discriminant analysis for sex determination. The accuracies obtained from the sex determination equations were greater than 90% for the direct and step-by-step methods. For the stepwise method, an equation requiring only six variables was developed. Relatively high percentage accuracy using fewer cranial measurements was performed by assessing maximum cranial length; bizygomatic width; binaural width; nasal height; maximum bio-orbital width; and mastoid length (right). The result was 90.6% for overall accuracy with 90.0% for men and 91.1% for women.

However, Fatah *et al*. (2014) [28] from skull tomography showed that important sexual variables are related to the size of certain anatomical structures, such as: the bizygomatic width, the maximum length of the skull, the length of the base of the skull, and the height of the mastoid. Variables related to shape indicated sexual differences in glabella projection, frontal inclination, and skull base flexion. The analysis obtained a precision greater than 95% (97.5% with 11 anatomical structures and 95.5% with eight anatomical structures).

DISCUSSION

The studies in this systematic review recognize the general shape of the mastoid process as the most used anatomical structure for sex determination [3]. However, it was observed that other anatomical structures also show a high degree of sexual dimorphism, including the glabella, supraorbital arch, frontal profile, and bizygomatic width [15–20,26–30].

As reported in the outcomes of this systematic review, sexual dimorphism can be characterized through qualitative and/or quantitative analyses, with advantages and disadvantages for each method [13,15,30]. The limitation of quantitative analyses is related to the lack of standardization of markings of the points of the mastoid process, making it difficult to compare studies. In addition, some studies use the height of the mastoid process, while others use its length [13,15,30]. Furthermore, ethnicity should be included in the assessment of any structures measured, as databases need to be updated regularly to reliably compare values [13,15,30]. This limitation is also found in qualitative analysis, as there may be changes in the shapes and sizes of anatomical structures according to each ethnic group [13,15,30]. However, qualitative analysis is also influenced by the professional's experience and by environmental influences, muscle action, and the individual's age [13,15,30].

Mahakkanukrauh *et al*. (2015) [20] analyzed twenty-five variables of measurement of anatomical structures, and concluded that determination of the sex of the skull quantitatively was adequate to predict the Thai male gender with high precision. These study findings provide strong evidence that the quantitative technique reveals greater precision, reliability, and confidence in sex determination compared to the qualitative method. [20]. In addition, the authors provided an efficient equation (91%) based on specific cranial measurements (maximum cranial length; bizygomatic width; binaural width; nasal height; maximum bio-orbital width; and right mastoid length) for determining the sex of the skull, especially when forensic osteologists are required to deal with fragmented skulls found in a forensic situation [20]. These data indicate that quantitative techniques, when well defined methodologically, can play an essential role in defining, or even collaborating in a complementary way with the qualitative assessment, particularly when these are necessary in view of the quality and condition of the skulls to be evaluated [20].

Regarding the anatomical structures evaluated, Garvin *et al.* (2014) [15] ranked the glabella and mastoid process as the most reliable sex discriminators in samples of white Americans, black Americans, medieval Nubians, and Native American Arikaras [15]. These results are consistent with Walker (2008) [21], and conclude that even if the population is unknown, cranial features can still provide highly accurate data on sex estimation results [15]. In addition, it is important to emphasize that significant differences can be noticed between the collections of Terry and Bass U.S. [15]. The Bass collection is more modern and exhibits more masculine cranial features (particularly in males) and greater sexual dimorphism than the Terry sample. This could be related to better socioeconomic status and lifestyle, differences in diet and nutrition, or changes in hormone levels across generations [15].

Certain features, such as the glabella for men and the mastoid process for women, do not fit the underlying premise of the method. [16]. These findings were supported by Godde *et al*. (2018) [16] when analyzing three temporally distinct groups that presented three different individual expression patterns. Men displayed more scores of 4 and 5, while women were morphology consistent with scores of 1 and 2 [16]. More specifically, Egyptian men received low or less robust scores for the glabella. [16]. Similarly, American and Egyptian women scored 3 (undetermined) more often than any other score for the mastoid process [16]. Although the method in Buikstra and Ubelaker (1994) is accurate for scoring sexes, population trends can cause professionals to misclassify an individual if ancestry is unknown [16]. Certain features are not available for scoring and/or incorrectly fit the method to population patterns in the scoring sample [16].

The study results of Soficaru *et al.* (2014) [19] are corroborated by those of the Walker method (2008) [21] for sex determination, based on the five cranial traits. In the Romanian sample, for men, values are higher than for Americans/English, but similar to Native Americans [19]. The glabella is more prominent in Romanians than in Americans/English and Native Americans, and the orbital margin is thicker in Romanians than in Americans/English [19]. The nuchal line has the same values as Native Americans, while the mastoid process is more robust than in the American specimens, and finally the mental eminence is greater than in the American/English and Native American specimens. [19]. For the Romanian sample, women received higher frequencies of lower scores than the American samples. [19]. The glabella is smoother than in American/English and Native American, the marginal orbit is as sharp as in American/English, the nuchal line is between the Native American and American/English, the mastoid process is smaller than in American/English specimens, and the mental eminence is also more delicate than in American samples [19].

With respect to sex identification among Africans, a higher level of inter- and intra-examiner agreement was noted for the glabella, mastoid process, and nuchal crest [18], suggesting that these anatomical structures are reliable for sex identification among Africans [19]. In addition, these structures presented the highest reliability values in sexual identification for all groups. In contrast, the study conducted by Banic *et al.* (2016) [6] was the only one of the eligible studies that obtained dissonant results, determining the mastoid process as the least reliable structure, and the nuchal line and orbital shape as the most reliable anatomical structures. It is worth considering that the sample consisted of medieval skulls from archaeological sites on the eastern coast of the Adriatic [6]. Despite the widespread use of the mentioned methods for sex assessment, there are no tests of their validity and reliability for different populations [6]. In addition, the study confirmed the population specificity of all morphological features of the skull and the reliability of the morphological features that provide the best results depending on the tested sample (Garvin, 2014; Kruger, 2015) [15,18].

It is pertinent to point out that when analyzing the strength of the association between the anatomical structures and sex and determining the morphological characteristics with greater diagnostic power for sex [29], the frontal profile presented the highest diagnostic reliability, followed by the superciliary arch [29]. The superciliary arch showed a high percentage of reliability in sexual identification, with a combined correct classification of 75.8%, and greater accuracy in male skulls than female skulls [29]. However, two studies reported that the glabella and mastoid process are the most reliable features for determining sex differences [15,18]. These authors reported 80% accuracy in sex determination using the glabella and mastoid process [15,18]. The highest accuracy (84% combined, 92% in men and 76% in women), was found using the 3 features: glabella, mastoid process, and chin [18,30]. Overall, the authors suggested that the mastoid process was the most accurate anatomical structure (84.75%), with good balance between sensitivity and specificity (92 and 80%, respectively)[18,30]. These data are consistent with a more recent report where the mastoid process was significantly associated with sex, with a sensitivity of 78% [29]. However, when the accuracy was analyzed through the morphognostic aspect of the anatomical structures, the prominence of the superciliary arch and glabella achieved 90% accuracy, followed by muscle insertions with 82% and the mastoid process with 75% [17].

In addition, the external projection (right and left) of the mastoid process showed a similar ability to identify men (69.6%) and women (74.7%) [26]. These data indicate that the measurements performed are just as useful for estimating the sex of male and female skulls, and for traditionally employed visual assessments. Furthermore, it is estimated that these quantitative measurements are another way of measuring the size and shape of anatomical structures [26]. Anthropologists have, however, good reason to choose quantitative methods over more subjective visual methods [26], as they provide a more efficient operation and a more accessible method to assess the shape of cranial structures than other current techniques [26].

Regarding the development of specific osteometric techniques, two studies indicated that the dimensions of anatomical structures in men are statistically significantly greater than in women [27,28]. Furthermore, bizygomatic width is the most discriminating single dimension and can provide an accuracy rate that can reach 88.2% [27]. Global analysis showed shape differences in the glabellar and mastoid region [28]. Thus, the importance of developing a more accurate method to assess anatomical structures for sex estimation of modern white Americans is highlighted, in order to improve classification rates on those currently published discriminant functions and provided with various combinations of these variables in relation to such structures. evaluated anatomy.

According to the results obtained in the studies of this systematic review, whether analyzed qualitatively or quantitatively, it can be stated that the temporal differences in the studied populations (ancient or modern collections) are much greater than the biological and geographic differences, similar to the Walker study (2008) [21] which also observed these differences [3,6,28–30,15–20,26,27]. With the data obtained from this review, it is concluded that distinct anatomical structures present a high degree of reliability in the identification of sexual dimorphism compared to the mastoid process. However, to date, no studies have provided a standardized method, which is capable of reproducing results, without errors of execution on behalf of the professional, and that provides updated averages of comparisons between the races, mainly for a population that presents high miscegenation. In this way, further studies and protocols are needed for the standardization and identification of sexual dimorphism using distinct anatomical structures in human identification from skulls. The limitation of the present work is that the studies evaluated presented heterogeneity in the data, making it impossible to perform a meta-analysis.

CONCLUSION

Even with the limitations of the present study, quantitative and qualitative analyses are essential in sexual identification from human skulls, and different anatomical structures, in addition to the mastoid process, can be used as references, with high reliability and precision, among them; glabella, frontal profile, superciliary arch, bizygomatic width, maximum cranial length, and nasal height. However, more robust and standardized trials are needed to confirm the results, with less heterogeneity and a higher quality of evidence.

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Apendix A

Search Strategy

P:

Termo Mesh: (Skulls) OR (Cranium) OR (Calvaria) OR (Calvarium)

Dentistry, Forensic

(Anthropology, Forensic) OR (Human Identification) OR (Human Identifications) OR (Identification, Human) OR (Identifications, Human)

I: Craniometry

(Mastoids) OR (Mastoid Process) OR (Mastoid Processes) OR (Process, Mastoid) OR (Mastoid Bone) OR (Bone, Mastoid) OR (Mastoid Bones) OR (Mastoid Foramen) OR (Foramen, Mastoid)

C: (Characteristic, Sex) OR (Sex Characteristic) OR (Sexual Dimorphism) OR (Dimorphism, Sexual) OR (Sexual Dimorphisms) OR (Gender Differences) OR (Gender Difference) OR (Sex Dimorphism) OR (Dimorphism, Sex) OR (Sex Dimorphisms) OR (Gender Characteristics) OR (Characteristic, Gender)OR (Gender Characteristic) OR (Gender Dimorphism) OR (Dimorphism, Gender) OR (Gender Dimorphisms) OR (Sex Differences) OR (Difference, Sex) OR (Sex Difference) OR (Sexual Dichromatism) OR (Dichromatism, Sexual) OR (Dichromatisms, Sexual) OR (Sexual Dichromatisms)

O:

Table 1 – General data on the selected studies.

Author / Year	**Country**	**Sample size**	**Sample source**	**Area analyzed**	**Intervention characteristics**	**Assessment instrument**	**Results**	**Conclusions**
Kranioti *et al.*, 2008 [24]	Greece	178	The cemeteries of St. Konstantinos and Pateles, Heraklion, Crete.	Maximum cranial length, basion–nasion length, maximum vault breadth, maximum frontal breadth, minimum frontal breadth bizygomatic breadth, foramen magnum length,	All dimensions are recorded in millimeters using a sliding and spreading caliper.	A comparison is made with several populations geographically and time wise distant from Cretans. The data are from the early 20th century White Americans (Terry collection) and South Africans Whites (Dart and Pretoria collections) Stepwise discriminant function analysis is used to select the combination of variables that best discriminate sexes. Differences between means are measured using Student's ttest. Data analysis is carried out using canonical discriminant function subroutines of SPSS.	Results indicate that males are statistically significantly greater than females in all dimensions. Bizygomatic breadth is the most discriminatory single dimension and can provide an accuracy rate of 82% on average. Using a stepwise method involving five dimensions (bizygomatic breadth, cranial length, nasion–prosthion and mastoid height and nasal breadth), accuracy is raised to 88.2%. Interestingly, cranial length is selected as the first discriminating variable by the stepwise analysis when only the neurocranium is available for measurement.	Sexual dimorphism in Cretans is well reflected in cranial dimensions, thus providing a very high accuracy rate of correct classification. From the forensic perspective this information is essential for the identification of skeletal remains. Hence, one should be very sceptical in expressing a definitive theory on the racial affinity of modern Cretans which exceed the main purpose of this study. A more detailed investigation of the shape and size components of sexual dimorphism

				foramen magnum breadth, basion–bregma height, basion–prosthion length, nasion–prosthion height, mastoid height, biorbital breadth, interorbital breadth,				must be carried out in order to define with better accuracy the special craniofacial characteristics of modern Cretans and the degree of isolation of the population compared with other groups in space and time. Further research may provide additional standards for Cretans and Greeks and hopefully will be applicable to other Mediterranean and Balkan populations.

				nose breadth nose height.				
Suazo *et al.*, 2009 [29]	Brazil	284	Collection of Universidade Federal de São Paulo - UNIFESP	16 estruturas: Size and architecture of the skull, forehead shape, frontal eminences, superciliary arches, orbital shape, piriform aperture, nasal bone, zygomatic bone,	The diagnostic tests based on the observation of the Morphological indicators of sexual dimorphism .	Indicators of sexual dimorphism were evaluated in terms of accuracy, intraobserver error sensitivity,positive predictive value, likelihood ratios, and odds ratio	All indicators studied had high levels of accuracy (84.75-72-89%). The best indicators of morphological sexual dimorphism based on overall accuracy, combined ranking and reliability, and odds ratio were the mastoid process, the zygomatic bone, mandible, and ridges of the occipital bone. Indicators with lower overall accuracy were shape of the palate, chin, and orbit.	The authors concluded that morphological dimorphism indicators present an adequate performance as diagnostic tests, however, the values of accuracy and sensitivity must be matched with more robust indicators that are independent of the distribution of the sample, and integrate diagnostic errors such as the likelihood ratios, odds ratios, and positive predictive values.

				zygomatic arch, parietal eminences, mastoid process, occipital bone, occipital condyles, shape of the palate, general appearance of the mandible, and chin shape				
Casado, 2013 [27]	EUA	264	The University of Tennessee's	Supraorbital ridge	Coordinate calipers capture the three-dimensional nature of	Lateral measuring tips of coordinate calipers placed on	Variable most correlated with the DFA is the projection of	Though more research is needed, this preliminary

			William M. Bass Collection The University of New Mexico's Documented Skeletal Collection housed at the Maxwell Museum	Glabella External occipital protuberance Nuchal protuberance Mastoid process Frontal bosses	the traits and provide a depth measurement for each feature.	defined cranial landmarks; central measuring tip drops down to record projection of feature • Six sexually dimorphic areas of the skull were measured •Measurements are of cranial features that are traditionally visually assessed and scored using an ordinal (1-5) scale • A discriminant function analysis was performed using SPSS	the right mastoid process (5Rdepth) Overall, 72.4% of the crania were correctly classified. Males were correctly classified 85% of the time, while females were correctly classified only 46.8% of the time, which is at a rate less than by chance alone	analysis suggests that the existing visual methods are adequate as sex estimation techniques and should be more than sufficient for courtroom testimony and application to a medico-legal context.
Garvin *et al.*, 2014 [16]	EUA	499	1) Bass Donated Collection U.S. Whites (Komar and Grivas, 2008), 2) Terry Collection U.S. Whites (Hunt and Albanese, 2005),	Nuchal Mastoid Orbital margin Glabella Mental eminence	Using a five-trait scoring system developed by Walker.	reported sex probabilities and discriminant functions	correct sex classification rates ranged from 74% to 94%, with an overall accuracy of 85% for the pooled sample. Classification performance varied among the traits (best for glabella and mastoid scores and worst for nuchal scores).	The results of this study suggest that age and body size (i.e., postcranial size) do not have great enough effects on cranial trait expressions to warrant their inclusion in sex estimation methods. Across all groups, glabella and mastoid scores were the

			3) Terry Collection U.S. Blacks (Hunt and Albanese, 2005), 4) Hamann-Todd Collection U.S. Blacks (Cobb, 1935), 5) Kulubnarti medieval Nubians (Van Gerven *et al*., 1995; Sandberg, 2006), 6) Arikara Native Americans (Jantz and Owsley, 1984; Owsley and Jantz, 1985). Collections are housed at the University of Tennessee (Bass and					most reliable sex indicators, while nuchal and mental eminence scores contributed little to sex estimation.

			Arikara), Smithsonian Institution National Museum of Natural History (Terry), Cleveland Museum of Natural History (Hamann-Todd), and the University of Colorado (Kulubnarti).					
Fatah *et al*., 2014 [25]	USA	222	William M. Bass Donated Skeletal Collection at the University of Tennessee's Department of Anthropology	Basion Glabella Inion Mastoidale Metopion Nasion	Models were constructed from 222 cranial CT scans	Models were constructed from 222 cranial CT scans. These models were used to create a statistical bone atlas that captures the primary shape variation in the skull and facilitates rapid computer-automated analyses.	The bone atlas showed that important size-related sex variables are bizygomatic breadth, maximum cranial length, cranial base length, and mastoid height. Shape-related variables capture sex differences in the projection of the glabellar region, inclination of the frontal, and cranial base flexion. In addition, vault thickness is highly dimorphic, with females having on average thicker vaults in the frontal region, and males having thicker vaults in the occipital region. Cross-validated linear discriminant analysis obtained >95%	The general nature of variation in cranial sexual dimorphism should be investigated to develop a better understanding of the areas greatest dimorphism in different populations.

				Ophistocranion Ophistion Porion Sella Supraglabella Vertex Zygion			accuracy (97.5% with 11 variables and 95.5% with eight variables)	
Soficaru *et al.*, 2014 [18]	Romania	360	The Rainer Osteolog-ical Collection	glabella area (G), the mastoid process (Ma), the mental eminence (M), theorbital edge (O)	Using a five-trait scoring system developed by Walker.	Was generate sex discriminant functions (logistic), selected the most accurate of them, and subsequently applied them to archaeological samples from Romania. Each skull feature showed significant scoredifferences by sex.	The discriminant logistic functions indicate a high level of correct sex classifications,frequently over 90%, even after applying the “leave one out” cross validation correction (LOO CV). Thecross validation procedure did not reduce by much the discriminating efficiency of the functions. Theunivariate method had the lowest percentage of correct predictions, e.g., with only 66% for femalesbased on the orbital trait.	The accuracy of the method may be influenced by geographical and historical differences which are bound to exist between populations. The results presented are promising and are expected to help establish more accurate criteria for sex determination based on visual

				the nuchal crest (N)					assessment of cranial features.
Kruger *et al.*, 2015 [17]	South Africa	245	Pretoria Bone Collection – Pretoria Anatomy Department	nuchal crest, mastoid process, glabella, supraorbital margin the mental eminence	Was scored according to the five standard morphoscopic traits for the cranium as presented by Walker		Cohen's kappa was used to evaluate reliability of the method, and percent correct assessed validity of the method. Logistic regression was utilised to create modified population-specific formulae.	Inter- and intra-observer agreement was moderate to excellent (0.60–0.90), except for the mental eminence (0.40). The percent correct results for sex were 80%or higher for combinations of glabella,mastoid andmenton and between 68 % and 73 % for menton, mastoid, orbital and nuchal margin using logistic equations of Walker (2008). White males had the highest (94–97 %) and White females had the lowest (31–62 %) percent correct.	The low accuracies obtained when using Walker's equations emphasised the need for population-specific sex estimation models. Modified formulae for South Africans were created, yielding higher classification rates (84–93 %) than when North American standards were employed.
Mahakkanukrauh *et al.*, 2015 [19]	Thailand	Thai	200	Forensic Osteology Research Center (FORC) in the Faculty of Medicine at Chiang Mai University	Maximum cranial length Maximum cranial breadth Bizygomatic breadth	Using either sliding calipers, or spreading calipers	Measurements 1-21 were taken according to the standards described by Buikstra and Ubelaker Three measurements (22, 24, and 25) were described by Jorgensen which derived from Martin's work. Measurement 23 followed the	The results revealed that males' cranium were statistically significant larger than females' in all measurements (P<0.05), except for minimum breadth of nasal bone. Sexual dimorphism index also expressed relatively high	The accuracies obtained from sex determination equations were higher than 90% for both direct and stepwise methods. For stepwise method, the equation, required only six variables was

					Basion-bregma heigh Cranial base length Biauricular breadth Minimum frontal breadth Upper facial breadth Nasal height Nasal breadth Orbital breadth Orbital height Biorbital breadth Interorbital breadth Frontal chord		procedures described by Dayal *et al*. and the bony landmarks are originally from Martin.	male/female ratio indicating great sexual dimorphism. The best practical equation for sex determination with six measurements (maximum cranial length, bizygomatic breadth, biauricular breadth, nasal height, biorbital breadth and right mastoid length) was derived from a stepwise discriminant method. This equation with 90.6% accuracy (91.1% in male and 90.0% in female) can provide valuable application utilizing in sex determination from skull in a Thai population	developed. It gave relatively high percentage accuracy with less required cranial measurements. This provided equation can be valuably applied in biological identification among Thai population, especially when fragmented skull was found in forensic cases.

					Parietal chord Occipital chord Foramen magnum length Foramen magnum breadth Mastoid length Mastoid length Maximum frontal breadth Basion-nasospinale length Biasterionic breadth Minimum breadth of nasal bone				
Ajanovic *et al.*, 2016 [15]	Bósnia e Herzegovina	211	Department of Human Anatomy of the School of	Prominence of frontal tuber;	Qualitative (osteoscopic) analysis was performed		Univariate binary logistic regression	All ten observed morphognostic skull features	univariately, the greatest predictive eff ect for prediction

			Medicine at the Sarajevo University.	prominence of superciliary arch and glabella; 104ppearance of supraorbital margin; 104ppearance of orbit; width of root of nose; prominence of mastoid process; contours of muscle insertions; size of teeth face shape.	through observation	was used to test the effect of morphological features on sexual dimorphism in skulls using male sex as dependent variable. Using the multivariate binary logistic regression, method BackWard:Wald in four steps, we tested the effect of independent variables (morphological features) on sexual dimorphism in skulls using male sex as dependent variable.	showed statistically signifi cant eff ect on sex determination, while prominence of superciliary arch and glabella proved to be the best morphognostic features with 90% accuracy, followed by prominence of muscle insertions with 82% accuracy, and prominence of mastoid process with 75% accuracy. Using multivariate binary logistic regression, we tested the eff ect of observed morphognostic features on sex determination and found that the only morphognostic features that had a statistically signifi cant eff ect on sex determination were prominence of superciliary arch and glabella and size of mastoid process. Multivariate eff ect of the prominence of muscle insertions on	of male sex is shown by the prominence of superciliary arch and glabella, prominence of muscle insertions and mastoid. Ince sexual dimorphism is differently reflected in different populations, there is a need for the establishment of a population-specific standard that would be used for sex determination within a particular population to reduce errors in sex determination. Our results provide smallscale population-specific standard that can be used for sex determination in future studies in Bosnian population.

							sex determination is borderline (p=0.052).	
Banic *et al.*, 2017 [6]	Croácia	40	Medieval archaeological sites of the eastern Adriatic coast area	Nuchal crest, mastoid process shape of the orbit.	Scored according to the five standard morphoscopic traits for the cranium as presented by Walker	Interclass correlation coefficient and Cohen value kappas were used to determine intrarater and interrater error.	The results obtained in this research showed that the reliability of the morphological evaluation skull characteristics depends on the experience of the researcher. Validity of the evaluation of morphological characteristics for the population studied on the east coast of the Adriatic, it is lower than that for which the standard was developed. Research has shown that it is important to know the reproducibility of resources for gender assessment and its influence on the result of the final classification. It is shown how important it is to know the accuracy classifications for the observed population and how there is population specificity in the features skulls showing sexual dimorphisms	It can be concluded that it is important to know the reproducibility of the features for gender assessment and their influence on the final classification result. It is also important to know the accuracy of the classification for the observed population. The examined morphological features of the skull showed that there is population specificity and are shown by sexual dimorphisms of the pronoun Discriminant functions used in data processing, made by Walker, do not show sufficient classification accuracy on the studied population and their use is not recommended.

Godde *et al.*, 2018 [23]	EUA	287 83 72	1 Hamann-Todd and William M. Bass Donated (Bass Collection) skeletal 106opulation 2 Averbuch site is in present day Middle Tennessee, more specifically, northwest of Nashville in Davidson County 3 collection housed in the Phoebe A. Hearst Museum at the University of California, Berkeley (UCB)	Nuchal Crest Mastoid Process Supraorbital Margin Glabella	The samples were scored 1–5, or discriminant functions derived from craniometrics.	Crania from these samples were scored 1–5, with 1 being consistent with expected female morphology. The estimated sex was compared to either documented sex (when available) or discriminant functions derived from craniometrics. Freeman-Fisher-Halton tests examined sample differences, within sexes, affecting the visual assessment method. Post hoc tests were applied to pinpoint where the differences lie between the samples.	The findings of this study support the hypothesis that the method does not estimate the sex of crania from all 106opulation in the same manner, indicating that 106opulation display differing patterns of sexual dimorphism. However, understanding these patterns and adjusting for how the method is applied will lead to reliable assessments.	Therefore, the expression of sexual dimorphism in these morphological traits is highly variable and follows specific population trends. Future research must focus its attention on documenting how traits should be weighted to account for this specificity.
Alves *et al.*, 2020 [26]	Chile	179	Departmentof Morphology and Genetics,	Frontal profile Superciliary arch	The morphological characteristics were analysed following the	The sensitivity and specificity were analysed for each variable	The frontal profile, the superciliary arch and the glabella presented the greatest sensitivity, best balance	All morphological characteristics of the skulls analysed, presented sexual

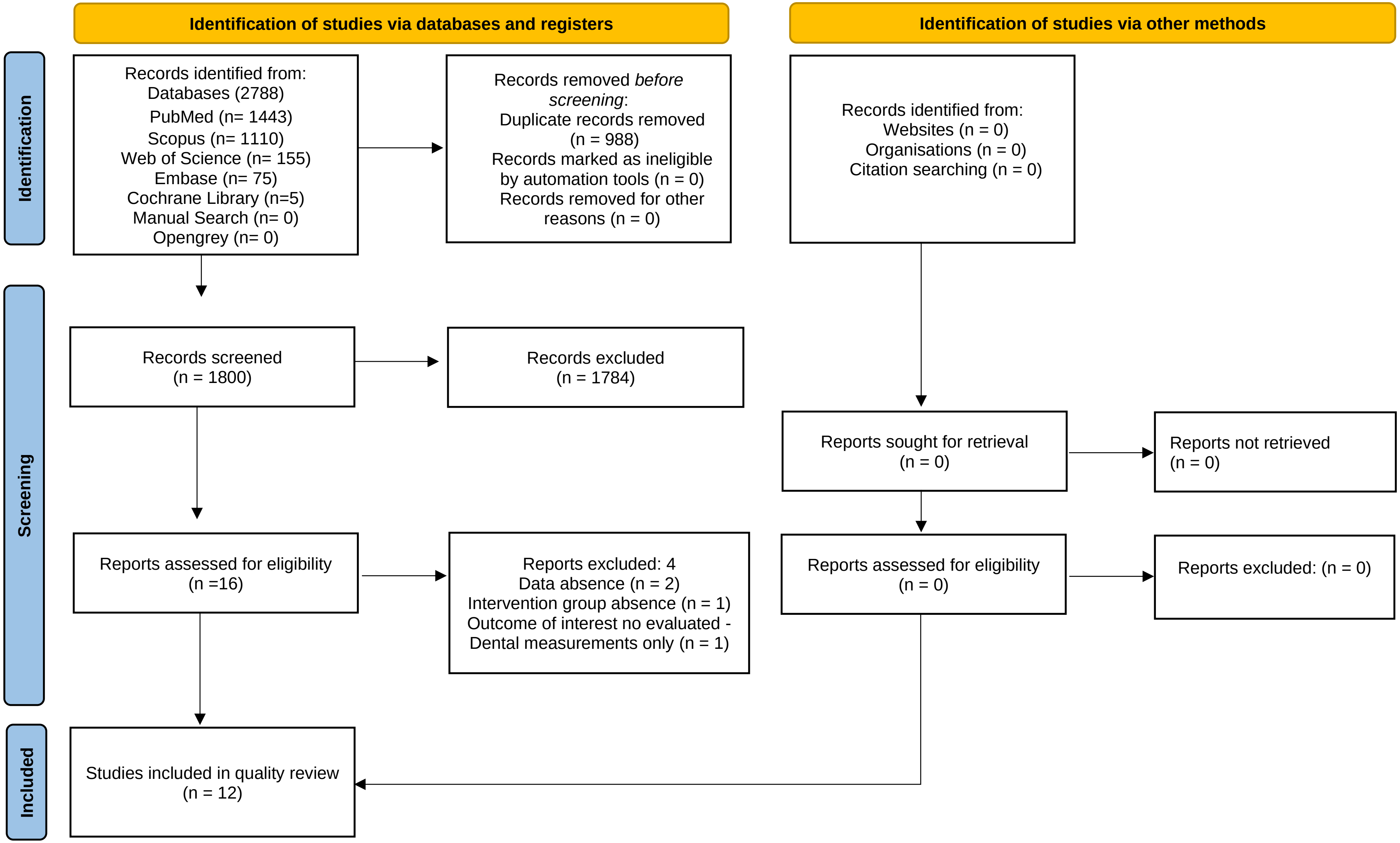
			UNIFESP (Brazil)	Glabella Zygomatic boné External occipital protuberance Mastoid process Nuchal plane Frontal and parietal eminences Zygomatic process of the temporal boné Shape of the orbit	classification of Walrath *et al*. (2004), in a modified version	and a ROC curve was constructed to analyse the best diagnostic test. A hierarchical binary logistic regression was carried out to determine whether the morphological characteristics of the skull can predict sex. The SPSS v.22 software was used, with a significance threshold of 5 %.	between sensitivity and specificity and greatest area under curve. The regression model with the frontal profile, superciliary arch and mastoid process was significant [X2(2) = 115,728 p=0.000, R2 Negelkerke=0.657], and presented correct sex classification in 90 % of cases (Males: 87.4 %; Females: 83.1 %).	dimorphism, however the frontal profile and the superciliary arch presented the highest degree of association with sex and the greatest power of sex diagnosis from skull samples. Sex determination using 3 morphological characteristics presented 90 % correct sex classification and 65.7 % sex prediction. In unknown individuals for whom the skull is present, non-metric analysis of the frontal profile, superciliary arch, mastoid process and glabella may be used for sex identification

Table 2. Risk of bias of included studies.

Criterion	Kranioti *et al.*, 2008 [24]	Suazo *et al.*, 2009 [29]	Casado, 2013 [27]	Garvin *et al.*, 2014 [16]	Fatah *et al.*, 2014 [25]	Soficaru *et al.*, 2014 [18]	Kruger *et al.*, 2015 [17]	Mahakkanukrauh *et al.*, 2015 [19]	Ajanovic *et al.*, 2016 [15]	Banic *et al.*, 2017 [6]	Godde *et al.*, 2018 [23]	Alves *et al.*, 2020 [26]
Ⅰ. Study design												
A. Objective clearly formulated	0	0	0	0	0	0	0	0	0	0	0	0
B. Sample size for each gender ≥ 30 subjects	0	0	0	0	0	0	0	0	0	0	0	0
C. Sampling method clearly reported	0.5	0.5	0	0	0	0	0	0	0	0	0	0
D. Inclusion criteria clearly reported	0.5	0.5	0	0	0	0	0	0	0.5	0.5	0	0
E. Origin of samples clearly reported	0	0	0	0	0	0	0	0	0	1	0	0
Ⅱ. Instruments taking process												
F. Measurement method—appropriate to the objective	0.5	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0
G. Subjects' Skull area/region clearly reported	0.5	0	0	0.5	0	0	0.5	0	0	0	0	0.5
H. Subjects- Skull distance clearly reported	1	1	0	0.5	0.5	0.5	1	0	0	0.5	0	0.5
I. Mastoid parameters clearly reported	0.5	0.5	0	0	0.5	0	0.5	0.5	0	0	0	0.5
Ⅲ. Area/region of Measurements												
J. Definitions of landmarks clearly described	0.5	0	0	0	0	0	0.5	0.5	1	0.5	0	1
K. Definitions of linear measurements clearly described	0	0.5	0	0	0	0	0.5	0.5	1	0.5	0.5	0.5
L. Definitions of angular measurements clearly described	1	0.5	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
M. Attempts to ensure and quantify reliability	1	0	0	0	0	0	0	0	1	0	0	1
Ⅳ. Statistical analysis												
N. Statistical analysis appropriate for data	0	0	0	0	0	0	0	0	0	0	0	0
O. Confounders accounted for in analysis	0	0.5	0.5	0	0	0	0	0	0	1	0	0
P. Confidence intervals provided	1	0	0	0	0	1	0	1	0	0	0	0
Percentage score	0.44	0.25	0.03	0.06	0.09	0.16	0.25	0.22	0.28	0.28	0.06	0.28
Risk of bias level	H	L	L	L	L	L	H	L	H	L	H	L

L: Low risk of bias; H: High risk of bias

Figure 1 - PRISMA flow chart— flow diagram showing the entire search process



Discussão Geral

A identificação humana é desafiadora para às Ciências Forenses, pois identificar a identidade de um ser humano é complexo e requer a utilização de métodos científicos que visam analisar as características morfológicas e morfométricas (ARAUJO *et al.*, 2014; BIANCALANA *et al.*, 2015; JAIN; JASUJA; NATH, 2013). Existem dois tipos de análises utilizadas para definir o perfil biológico, a qualitativa que é a análise morfológica ou subjetiva das estruturas anatômicas, e a quantitativa que é a análise morfométrica na qual é realizada através da marcação de pontos e medição dos mesmos (ARAUJO *et al.*, 2014; BIANCALANA *et al.*, 2015; JAIN; JASUJA; NATH, 2013). Consistem primeiramente na identificação do sexo, idade, ancestralidade e estatura, com finalidade de identificar o indivíduo (ALMEIDA *et al.*, 2010; PETAROS *et al.*, 2015b).

No entanto algumas limitações são encontradas em ambos os tipos de análises, na análise qualitativa pode haver alterações em formas e tamanhos das estruturas anatômicas de acordo com cada grupo étnico (GARVIN; SHOLTS; MOSCA, 2014; SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2008, 2009). No entanto, a análise qualitativa conta também com a influência da experiência do profissional e pelas influências ambientais, ação musculares e a idade do indivíduo (GARVIN; SHOLTS; MOSCA, 2014; SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2008, 2009). A limitação da análise quantitativa está relacionada a etnia avaliada independente das estruturas mensuradas, uma vez que os bancos de dados precisam ser criados ou atualizados regularmente para fazer a comparação dos valores de forma confiável (GARVIN; SHOLTS; MOSCA, 2014; SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2008, 2009).

A identificação humana e determinação do dimorfismo sexual pode ser realizada diretamente no crânio seco, através de análise visual ou utilizando equipamentos, como um paquímetro. Entretanto existem outras formas e ferramentas que podem ser utilizadas para realizar tais análises, como exemplo a radiografia, tomografia, escaneamento e a fotografia do crânio, garantindo maior acurácia para a identificação e padronização dos métodos (GARVIN; STOCK, 2016)

A fotogrametria é uma opção acessível que permite a reconstrução da posição, orientação, forma e tamanho, além de não requerer um hardware caro, e ainda é possível contar com vários softwares gratuitos permitindo a realização de análises quantitativa e qualitativa a fim de identificar o sexo do indivíduo (CAPLE; BYRD; STEPHAN, 2018a; CAPLE; STEPHAN, 2017; GARVIN; STOCK, 2016; GIBELLI *et al.*, 2017, 2019; JUNG; WOO, 2016; JURDA; URBANOVÁ, 2016; NIKITA, 2019a; NIKITA; MICHOPOULOU, 2018). E ainda com o estudo de Omari *et al,* 2021 (OMARI *et al.*, 2021) demonstrou que não é necessário o uso de câmera profissional, pois as fotografias foram realizadas com a câmera de um celular (OMARI *et al.*, 2021). E que a fotogrametria pode dar resultados tão precisos quanto os obtidos a partir de teste físicos e medidas de tomografia computadorizada sendo um método confiável e capaz de reproduzir (OMARI *et al.*, 2021).

Em ambas as revisões sistemáticas o processo mastóide foi avaliado com exceção do estudo Caple *et al*. (2017) (CAPLE; STEPHAN, 2017) que avaliou o crânio em norma frontal e lateral esquerda, e o estudo de Çelbis *et al.* (2001) (ÇELBIŞ *et al.*, 2001) que avaliou a região glabelar. O processo mastóide comprovou ser uma estrutura anatômica com alto dimorfismo sexual e confiável, com exceção do estudo de Banic *et al.* (2016) (MAGDA BANIĆ, ŽELJANA BAŠIĆ, 2016).

Isso reitera as observações dos primeiros autores antropológicos, que reconheceram a forma geral do processo mastoide como sendo a característica mais utilizada para a determinação do sexo (PETAROS *et al.,* 2015a) devido as suas características anatômicas, sua localização e robustez sendo possível ser analisado mesmo em crânios fragmentados e queimados, tornando-se uma estrutura padrão ouro em relação ao dimorfismo sexual (DE PAIVA; SEGRE, 2003; PETAROS *et al.*, 2021).

No entanto, deve-se avaliar mais que uma estrutura para melhor precisão e confiabilidade dos dados (GARVIN; SHOLTS; MOSCA, 2014), pois fatores intrínsecos e extrínsecos podem influenciar na ocorrência de estruturas com variações anatômicas que apresentam características contraditórias ou ambíguas em relação ao dimorfismo sexual (GARVIN; SHOLTS; MOSCA, 2014). Há evidências que a diminuição da ação muscular, desnutrição grave, e a atrofia pode diminuir a precisão desses métodos (SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2008). Como exemplo de estruturas anatômicas com alto grau de dimorfismo sexual, mas que podem ser afetadas por forças biomecânicas, tais como: a crista nucal, glabela, e o processo mastóide, pois são locais de inserções musculares para funções como movimento das sobrancelhas, cabeça e pescoço (GODDE; THOMPSON; HENS, 2018).

No entanto, outras estruturas anatômicas também apresentam alto grau de dimorfismo sexual, além do processo mastoíde, dentre elas a glabela, arco supraorbitário, perfil frontal e largura bizigomática (AJANOVIĆ *et al.*, 2019; ALVES *et al.*, 2020; CASADO, 2017; FATAH *et al.*, 2014; GARVIN; SHOLTS; MOSCA, 2014; GODDE; THOMPSON; HENS, 2018; KRANIOTI; IŞCAN; MICHALODIMITRAKIS, 2008; KRÜGER *et al.*, 2015; MAHAKKANUKRAUH *et al.*, 2016; SOFICARU *et al.*, 2014; SUAZO GALDAMES; ZAVANDO MATAMALA; SMITH, 2009).

Porém, até o momento, nenhum estudo forneceu um método padronizado, que seja capaz de reproduzir sem erros de execução por parte do profissional, e que forneça médias atualizadas de comparações entre as raças, principalmente para uma população que apresenta alta miscigenação. Desta forma, mais estudos e protocolos são necessários para a padronização e determinação do dimorfismo sexual utilizando a fotogrametria que é um método de extrema importância, e de fácil acesso, além do baixo custo é um método que apresenta alto grau de confiabilidade na determinação do dimorfismo sexual e identificação humana, e por poder substituir a tomografia, visto que alguns centros não possuem aparelhos de tomografia devido ao alto custo do aparelho e dos softwares. E em relação a seleção das estruturas anatômicas distintas do processo mastóide e/ou em conjunto com outras estruturas anatômicas na determinação do dimorfismo sexual e identificação humana a partir de crânios, também são necessários mais estudos e protocolos para a padronização. A limitação do presente estudo é que os estudos avaliados apresentaram heterogeneidade nos dados, em ambas as revisões impossibilitando a realização de metanálise.

Conclusão Geral

As análises quantitativas e qualitativas são essenciais na identificação sexual de crânios humanos. Mesmo com as limitações do estudo, a fotogrametria é um método viável e confiável na identificação do dimorfismo sexual de crânios. E em relação as diferentes estruturas anatômicas além do processo mastóide com alta confiabilidade e precisão, cabe ressaltar; glabela, perfil frontal, arco superciliar, largura bizigomática, comprimento craniano máximo e altura nasal. No entanto, estudos mais robustos e padronizados são necessários para confirmar os resultados, com menor heterogeneidade e maior qualidade de evidência.

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DECLARAÇÃO DE USO EXCLUSIVO DE ARTIGO EM DISSERTAÇÃO/TESE

Declaramos estarmos cientes de que o trabalho " A systematic review of photogrametry as a reliable methodology in gender identification of human skull" será apresentado na Tese da aluna Juliana Calistro da Silva e que não foi e nem será utilizado em outra dissertação/tese dos Programas de Pós-Graduação da FOB-USP.

Bauru, 21 de junho de 2023.

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