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# Sex Estimation through the Study of Computed Tomography of the Mandible

# *Procjena spola na temelju proučavanja kompjutorizirane tomografije mandibule*

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**Abstract**
**Objectives:** This study investigated the potential of the mandible as an anatomical structure for sex estimation using three-dimensional images generated by computed tomography. **Materials and Methods:** The research was conducted on 93 dry mandibles from the ICB-USP collection, aged over 18 years, and analyzed through 12 external measurements performed in the Meshmixer® software. **Results:** The data were subjected to binomial logistic regression and ROC curve analysis, revealing areas under the curve between 0.61 and 0.76, sensitivity between 55.36% and 80.36%, and specificity between 51.35% and 78.38% with ramus length, mandibular body height, and angle width as the most accurate. The study reinforces the feasibility of using tomography as an alternative to direct physical analysis of bones, especially when access to osteological specimens is limited. It highlights the importance of validating methods in multiracial populations such as the Brazilian. **Conclusion:** It is concluded that mandibular anthropometric analysis by tomographic images is a complementary tool in forensic sex identification, with practical applicability when recovery of complete skeletal material is difficult.

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## Introduction

The process of identifying an individual postmortem involves several steps. In many cases, primary identification methods (DNA analysis, fingerprinting, and forensic dentistry) are unfeasible due to decomposition, the conditions of the place where the body was found, and in mass disasters, homicides, or partial bone findings (1).

Forensic anthropology plays a well-established role in international studies in basic partial identifications, such as biological sex, geographic affinity, height, and age (2,4). In cases of advanced decomposition, the mandible may detach from the skull, making identification difficult by methods that use anthroposcopic and anthropometric analyses of the skull and mandible together (5).

Sex estimation is one of the initial steps in identifying bone findings and is essential for the final identification of an individual (6). Several studies use anthropometric analyses to estimate sex, mainly applicable to the pelvis, which is considered the most efficient bone region for such estimation in forensic anthropology (7–10). However, not all bones are

## Uvod

Postupak identifikacije pojedinca poslije smrti sastoji se od nekoliko koraka. Često primarne metode identifikacije (analiza DNK, otisci prstiju i forenzička stomatologija) nisu moguće zbog raspadanja, uvjeta na mjestu gdje je tijelo pronađeno, te u slučaju masovnih katastrofa, ubojstava ili djelomičnih nalaza kostiju (1).

Forenzička antropologija često se koristi u međunarodnim studijama za osnovne djelomične identifikacije, kao što su biološki spol, geografska pripadnost, visina i dob (2, 4). Ako je raspadanje već uznapredovalo, donja čeljust može se odvojiti od lubanje, što otežava identifikaciju metodama koje se upotrebljavaju tijekom antroposkopskih i antropometrijskih analiza lubanje i donje čeljusti zajedno (5).

Procjena spola jedan je od početnih koraka u identificiranju nalaza kostiju i ključna je za konačnu identifikaciju pojedinca (6). Autori nekoliko studija koristili su se antropometrijskim analizama za procjenu spola, a uglavnom su ih primjenjivali kad je riječ o zdjelici koja se u forenzičkoj antropologiji smatra najučinkovitijom koštanom regijom za takvu

always found. Skull bones are also widely studied, and several methods have been developed and validated in different populations to expand the techniques applicable to different identification scenarios (11-13).

The mandible is a unique bone with several points of sexual dimorphism (14). Qualitative analyses can be subjective and at risk of interobserver error due to the difficulty in establishing consistent parameters (4, 7). Quantitative methods have been applied to samples from different populations, with a greater chance of achieving correct identification (15–22). Access to collections containing mandibles worldwide is limited, making them valuable for studies using anthropological methods. The diversity of studies and the application of different methods are essential in this context (23).

With the advancement of technology and greater access to it, computed tomography (CT) has been used as an auxiliary and facilitating method to estimate sex (24,25) and other aspects such as age (26). It is recognized that access to certain technologies is limited for forensic researchers who work on the identification front line. However, it is necessary to consider the possible benefits of technology, such as data sharing without requiring the professional's physical presence (15, 27–29). This has increased the use of CT images for sex estimation analyses.

The mandible has significant dimorphic points that need to be studied and validated. This is essential for applying different methods, which can support and facilitate the identification process for forensic professionals. Studies show that anthropometric mandible analyses have a high dimorphic potential for correct sex estimation (30–34). However, few Brazilian studies have exclusively used the mandible and three-dimensional (3D) images as a basis for sex estimation, which justifies the importance of this study. Therefore, this study aimed to estimate sex in a sample of Brazilian mandibles.

## Materials and Methods

### Sample data and study context

This cross-sectional study was initially submitted to the Research Ethics Committee of the University of São Paulo under consolidated approval n. 4.465.406 (CAAE: 40722420.8.0000.0075). The study began after the research had been approved. Its sample consisted of dried mandibles belonging to the collection of the Museum of Human Anatomy of the University of São Paulo, located at the Institute of Biomedical Sciences Hall III (ICB-USP).

The sample consists of an identified osteological collection. At the time of death, data on sex, date of birth, date of death, and racial designation ("skin color") were recorded by cemetery authorities between 1913 and 1962. The cemeteries from which the sample originated are located in the city of São Paulo, Brazil, a metropolis that currently has more than 12 million inhabitants. Exhumations were carried out after a legally established period had elapsed, during which the family did not claim responsibility for the remains, thus making them available for research purposes (following approval by a Human Research Ethics Committee) (23).

procjenu (7 – 10). No ne pronađu se uvijek sve kosti. Kosti lubanje također su često i detaljno proučavane, a razvijeno je i validirano nekoliko metoda u različitim populacijama kako bi se proširile tehnike primjenjive na različite metode identifikacije (11 – 13).

Donja čeljust jedinstvena je kost s nekoliko točaka spolnoga dimorfizma (14). Kvalitativne analize mogu biti subjektivne i izložene riziku od pogreške među promatračima zbog poteškoća u uspostavljanju konzistentnih parametara (4, 7). Kvantitativne metode primjenjuju se na uzorke iz različitih populacija, s većom vjerojatnošću da će se postići ispravna identifikacija (15 – 22). Pristup zbirkama diljem svijeta koje sadržavaju donje čeljusti ograničen je, što ih čini vrijednima autorima studija koji se koriste antropološkim metodama. Raznolikost studija i primjena različitih metoda bitne su u ovom kontekstu (23).

S napretkom tehnologije i većim pristupom modernim uređajima, kompjutorizirana tomografija (CT) pomoćna je i olakšavajuća metoda za procjenu spola (24, 25) i drugih aspekata poput dobi (26). Poznato je da je forenzičkim stručnjacima koji rade na prvoj crti identifikacije ograničen pristup određenim tehnologijama. No potrebno je razmotriti moguće prednosti tehnologije, poput dijeljenja podataka bez potrebe za fizičkom prisnošću stručnjaka (15, 27 – 29). To je povećalo korištenje CT slika za analize procjene spola.

Čeljust ima značajne dimorfne točke koje je potrebno proučiti i validirati. To je bitno za primjenu različitih metoda koje forenzičkim stručnjacima mogu olakšati proces identifikacije. U studijama autori pokazuju da antropometrijske analize čeljusti imaju visok dimorfni potencijal za točnu procjenu spola (30 – 34). No autori malo brazilskih studija isključivo su se koristili donjom čeljusti i trodimenzionalnim (3D) slikama kao osnovom za procjenu spola, što opravdava važnost ove studije. Stoga je njezin cilj bio procijeniti spol na uzorku donjih čeljusti brazilske populacije.

## Materijali i metode

### Podatci uzorka i kontekst studije

Ova presječna studija izvorno je predana Odboru za istraživačku etiku Sveučilišta u São Paulu pod konsolidiranim odobrenjem br. 4.465.406 (CAAE: 40722420.8.0000.0075). Istraživanje je počelo nakon što je studija odobrena. Uzorak se sastojao od osušenih mandibula iz zbirke Muzeja ljudske anatomije Sveučilišta u São Paulu smještenog u Institutu za biomedicinske znanosti, dvorana III (ICB-USP).

Uzorak se sastoji od identificirane osteološke zbirke. Vrijeme smrti, podatke o spolu, datumu rođenja, datumu smrti i rasnim oznakama (boja kože) zabilježili su zaposleni na groblju između 1913. i 1962. Groblja s kojih potječe uzorak nalaze se u gradu São Paulu u Brazilu, metropoli u kojoj trenutačno živi više od 12 milijuna stanovnika. Ekshumacije su obavljene nakon isteka zakonski određenog razdoblja tijekom kojega obitelj nije preuzela odgovornost za posmrtne ostatke, te su postali dostupni za istraživačke svrhe (poslije odobrenja Etičkog odbora za istraživanje ljudi) (23).

## Data collection and eligibility criteria

The study included 93 dry, intact, unfractured mandibles from individuals aged 18 years or older. These mandibles had all anterior incisors preserved and at least two posterior teeth, either premolars or permanent molars. All mandibles from individuals under 18 years old, edentulous mandibles, those that did not meet the criteria for minimum teeth, fractured mandibles, and those with pathologies and malformations were excluded from the sample Figure 1.

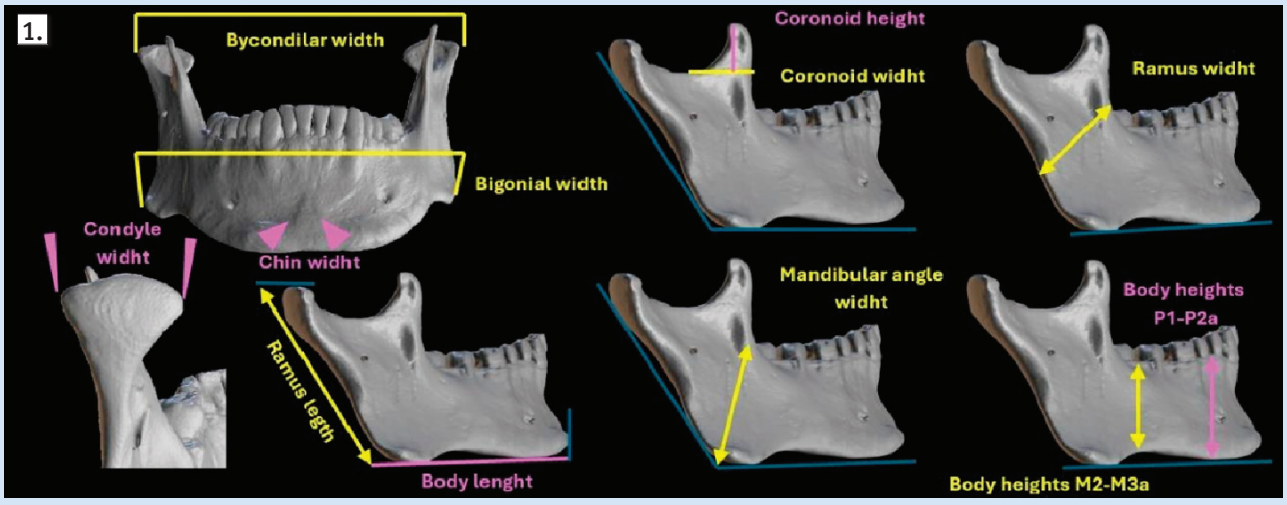
The mandibles belonging to the ICB-USP collection underwent CT scans at the University Hospital of the University of São Paulo (HU-USP), using Philips Brilliance 64® CT equipment. The CT images comprised the skull and mandible, but they were not articulated when the images were taken. Therefore, the volumetric 3D images of the mandible were subsequently obtained in DICOM format using the Blue Sky Plan 4® software. After volumetric reconstruction, the mandibles were isolated, and the skull was excluded from the sample. Then, the 3D images were converted to STL format and saved in a separate file for anthropometric analysis with the Meshmixer® software.

## Prikupljanje podataka i kriteriji prihvatljivosti

U studiji su analizirane 93 suhe, intaktne, nefrakturirane mandibule osoba u dobi od 18 godina ili više. Kod tih mandibula sačuvani su svi prednji sjekutići i najmanje dva stražnja zuba, bilo pretkutnjaci ili trajni kutnjaci. Sve mandibule osoba mlađih od 18 godina, bezube mandibule, one koje nisu zadovoljavale kriterije za minimalni broj zuba ili su bile frakturirane, te one s patologijama i malformacijama isključene su iz uzorka (slika 1.).

Mandibule iz kolekcije ICB-USP-a skenirane su CT-om u Sveučilišnoj bolnici Sveučilišta u São Paulu (HU-USP), a za to je korištena Philips Brilliance 64®. CT snimke obuhvaćale su lubanju i mandibulu, ali nije artikulirano kada su snimljene. Zato su volumetrijske 3D slike mandibule naknadno dobivene u formatu DICOM s pomoću softvera Blue Sky Plan 4®. Poslije volumetrijske rekonstrukcije mandibule su izolirane, a lubanja je isključena iz uzorka. Zatim su 3D slike pretvorene u format STL i spremljene u zasebnu datoteku za antropometrijsku analizu s pomoću softvera Meshmixer®.

Sve analize i postupke obavio je jedan, prije toga kalibrirani ispitivač. Analiza slaganja promatrača provedena je na-



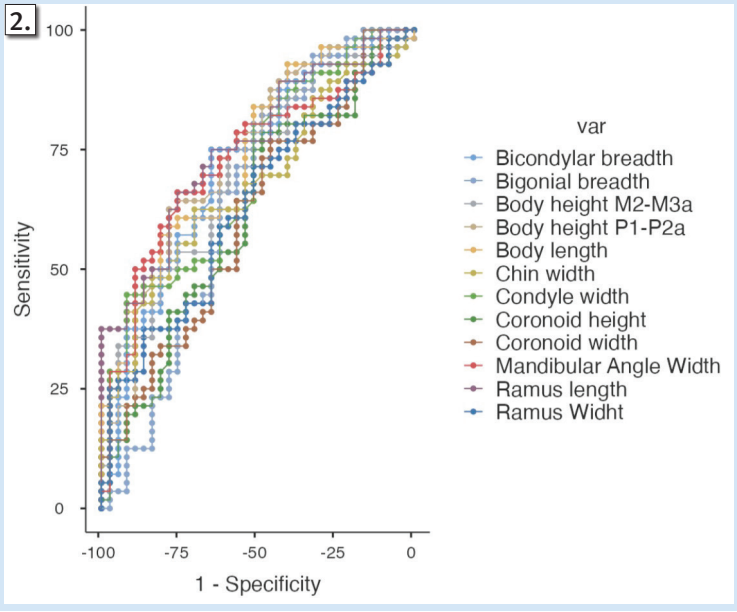




**Figure 1** External mandible measures.
**Slika 1.** Mjere vanjske mandibule

**Figure 2** Sensitivity and specificity data obtained through the ROC curve.
**Slika 2.** Podatci o osjetljivosti i specifičnosti dobiveni krivuljom ROC

A single, previously calibrated examiner performed all analyses and processes. The intraobserver agreement analysis was performed blindly with an interval of 15 days; the examiner applied the method to 20 mandibles and, after 15 days, the method was reapplied to the same mandibles. The intraobserver error was determined for all 12 measurements applied, individually.

The anthropometric analysis consisted of measuring 12 external anatomical points described by Tunis (30), as shown in Figure 1. The mandibular angle measure was excluded from the study due to its high rate of intraobserver bias. Internal mandible measures were also excluded because this study aimed to analyze only their external measures. The measures were taken using the Meshmixer® software, as shown in Figure 1. All 12 mandibular measures were taken through volumetric analyses of the sample mandibles, which were analyzed from the front, side, and back views, according to the needs of each structure analyzed. All data were entered into a Microsoft Office Excel® spreadsheet.

### Data analysis

Quantitative measures were used to analyze the results.

For the analysis of the anthropometric technique applied in this study, Binomial Logistic Regression was used to model the relationship of the binary variable for sex (0 for male and 1 for female) and the interdependent variables (different mandibular measures).

Sensitivity and specificity were calculated using ROC curves based on mandibular measures, determining the area under the curve (AUC) with a 95% confidence interval.

Statistical analyses were conducted using Jamovi® software, version 2.3.28.0 (Computer Software) retrieved from https://www.jamovi.org), considering significance for p-values < 0.05.

## Results

Among the 93 mandibles, 56 (60.21%) were male and 37 (39.79%) were female. The mean age of the male sample was 33.85 years, and that of the female sample was 34.40 years. Also, documented background of the sample is described in Table 1.

Model adjustment measures were obtained for the anthropometric analysis applied in this study, with statistically significant values ($p < .001$), described in Tables 2 and 3.

Results were obtained to measure the sensitivity and specificity of the technique applied to mandibular measures, as shown in Table 4. Among the 12 mandibular measures, the cutoff points ranged from a minimum of 15.63 to a maximum of 113.67. Sensitivity percentages ranged from 55.36% to 80.36%, and specificity percentages ranged from 51.35% to 78.38%. The AUC ranged from 0.61 to 0.76 (Table 4).

The sensitivity and specificity values for the different cutoffs demonstrated that the mandibular measures (bicondylar width, body length, body height P1-P2, body height M2-M3, condylar width, mandibular angle width, and ramus length) had percentages above 60% for sensitivity and above 65% for specificity.

slijepo s razmakom od 15 dana; ispitivač je primijenio metodu na 20 mandibula i poslije 15 dana metoda je ponovno primijenjena na iste mandibule. Pogreška promatrača određena je pojedinačno za svih 12 primijenjenih mjerenja.

Antropometrijska analiza sastojala se od mjerenja 12 vanjskih anatomskih točaka koje je opisao Tunis (30), kao što je prikazano na slici 1. Mjerenje kuta mandibule isključeno je iz studije zbog visoke stope pristranosti promatrača. Unutarnje mjere mandibule također su isključene jer je svrha ove studije bila analizirati samo njihove vanjske mjere. Mjere su dobivene s pomoću softvera Meshmixer®, kao što je prikazano na slici 1. Svih 12 mjera mandibule dobiveno je volumetrijskom analizom uzoraka, a analizirane su s prednje, bočne i stražnje strane, prema potrebama svake analizirane strukture. Svi podatci uneseni su u proračunsku tablicu programa Microsoft Office Excel®.

### Analiza podataka

Za analizu rezultata korištene su kvantitativne mjere.

Za analizu antropometrijske tehnike primijenjene u ovom istraživanju korištena je binomna logistička regresija za modeliranje odnosa binarne varijable za spol (0 za muškarce i 1 za žene) i međuovisnih varijabli (različite mandibularne mjere).

Osjetljivost i specifičnost izračunate su s pomoću krivulja ROC na temelju mandibularnih mjera, određujući površinu ispod krivulje (AUC) s intervalom pouzdanosti od 95 % (slika 2.)

Statističke analize obavljene su u softveru Jamovi®, verzija 2.3.28.0 (računalni softver), a preuzet je s https://www.jamovi.org), uzimajući u obzir značajnost za p-vrijednosti < 0,05.

## Rezultati

Među 93 mandibule, njih 56 (60,21 %) pripadalo je muškarcima, a 37 (39,79 %) ženama. Prosječna dob muškog uzorka bila je 33,85 godina, a ženskoga 34,40. Dokumentirana pozadina uzorka opisana je u tablici 1.

Mjere prilagodbe modela dobivene su za antropometrijsku analizu primijenjenu u ovoj studiji, sa statistički značajnim vrijednostima ($p < 0,001$) opisanim u tablicama 2. i 3.

Rezultati su dobiveni za mjerenje osjetljivosti i specifičnosti tehnike primijenjene na mjere mandibule, kao što je prikazano u tablici 4. Kad je riječ o 12 mjera mandibule, granične vrijednosti kretale su se od minimalnih 15,63 do maksimalnih 113,67. Postotci osjetljivosti bili su od 55,36 % do 80,36 %, a postotci specifičnosti od 51,35 % do 78,38 %. AUC se kretao od 61 do 0,76 (tablica 4.).

Vrijednosti osjetljivosti i specifičnosti za različite granične vrijednosti pokazale su da su mandibularne mjere (širina bikondila, duljina tijela, visina tijela P1 – P2, visina tijela M2 – M3, širina kondila, širina kuta mandibule i duljina ramusa) imale postotke više od 60 % za osjetljivost i iznad 65 % za specifičnost.

**Table 1** Sociodemographic characteristics of the sample.
**Tablica 1.** Sociodemografske karakteristike uzorka

| | | n | % | Mean age (yrs.) |
|---|---|---|---|---|
| Sex | Male | 56 | 60.21 | 33.85 |
| | Female | 37 | 39.79 | 34.40 |
| Documented background | African | 42 | 45.16 | |
| | European | 30 | 32.26 | |
| | Asian | 18 | 19.35 | |
| | No information | 03 | 03.23 | |

**Table 2** Model adjustment measures.
**Tablica 2.** Mjere prilagodbe modela

| Model | Deviation | AIC | $R^2_{CS}$ |
|---|---|---|---|
| 1 | 105.74 | 109,74 | 0,15 |

Caption: AIC (Akaike Information Criterion)

**Table 3** Model coefficients – ACTUAL SEX (0 = male; 1 = female).
**Tablica 3.** Koeficijenti modela – STVARNI SPOL (0 = muško; 1 = žensko)

| Predictor | Estimates | Standard error | Z | P |
|---|---|---|---|---|
| Interceptor | 10,39 | 2,78 | 3,74 | <.001 |
| Branch length | -0,18 | 0,05 | -3,88 | <.001 |

Caption: Estimates represent the log odds of "ACTUAL SEX (0 = male; 1 = female) = 1" vs. "ACTUAL SEX (0 = male; 1 = female) = 0"

**Table 4** Measurement of anthropometric properties of mandibular measures.
**Tablica 4.** Mjerenje antropometrijskih svojstava mjera mandibule

| Measures | Cut-off point | Sensitivity (%) | Specificity (%) | Area under the curve |
|---|---|---|---|---|
| Ramus length | 62.2 | 71.43 | 67.57 | 0.76 |
| Ramus width | 31.86 | 55.36 | 64.86 | 0.63 |
| Body length | 88.98 | 60.71 | 75.68 | 0.74 |
| Body height P1-P2* | 29.59 | 62.5 | 78.38 | 0.74 |
| Body height M2-M3** | 23.87 | 73.21 | 59.46 | 0.70 |
| Mandibular angle width | 31.53 | 60.71 | 78.38 | 0.73 |
| Coronoid width | 19.84 | 64.29 | 56.76 | 0.61 |
| Coronoid height | 15.63 | 75.00 | 51.35 | 0.62 |
| Condyle width | 17.58 | 80.36 | 51.35 | 0.70 |
| Chin width | 16.87 | 62.5 | 70.27 | 0.68 |
| Bicondylar breadth | 113.67 | 75.00 | 64.86 | 0.72 |
| Bigonial breadth | 91.53 | 71.43 | 56.76 | 0.64 |

Caption: * P1 (first premolar) / P2 (second premolar) / ** M2 (second molar)/ M3 (third molar).

The ROC Curve (Figure 2) demonstrates the result of integrating all cutoffs simultaneously with the sensitivity and specificity values, estimating the overall test accuracy. The AUC was above 0.60 in all mandibular measures, with values between 0.61 and 0.76.

## Discussion

The Brazilian population exhibits high genetic admixture due to historical immigration waves. This diversity poses a challenge for anthropometric analysis in forensic anthropology, where human identification increasingly relies on digital imaging technologies. Consequently, optimizing these anthropometric techniques has become a key focus in several recent studies (35–37). Forensic anthropology has difficulty in accessing collections and samples and acquiring new pieces due to each country's ethical and legal issues, which limit maceration processes to obtain osteological pieces (38). Using CT scan images is an alternative, considering

Krivulja ROC (grafikon 1.) pokazuje rezultat integriranja svih graničnih vrijednosti istodobno s vrijednostima za osjetljivost i specifičnost, procjenjujući ukupnu točnost testa. AUC je bio iznad 0,60 u svim mandibularnim mjerama, s vrijednostima između 0,61 i 0,76.

## Rasprava

Brazilska populacija pokazuje visoku genetsku primjesu zbog povijesnih imigracijskih valova. Ta je raznolikost izazov za antropometrijsku analizu u forenzičkoj antropologiji zato što se identifikacija ljudi sve češće oslanja na tehnologije digitalnog snimanja. Posljedično, optimizacija tih antropometrijskih tehnika postala je ključna u nekoliko nedavnih studija (35 – 37). Forenzička antropologija ima poteškoća u pristupu zbirkama i uzorcima te u nabavi novih predmeta zbog etičkih i pravnih problema svake zemlje, što ograničava procese maceracije za dobivanje osteoloških

the greater ease of access and the fact that physical analysis of the samples is unnecessary, thus preserving collections and pieces for future generations (23).

It is known that CT images can be used for forensic purposes during human identification. Once they are reconstructed in 3D, sex, age, height, and geographic affinity can be estimated, as well as in necessarily physical techniques to approach bone findings (2,39). The literature portrays the pelvis, skull, and mandible (in this order) as the bone regions with the best results among those with the greatest dimorphic potential (35).

The structures of the mental protuberance and mandible body length are among the measures with the greatest dimorphic potential, as shown in the results of this study.

The mandible, due to its shape and thickness, is one of the bones frequently found in mass disasters and crime scenes. Moreover, it is possible to estimate a person's biological characteristics through methods that use anthropometric measurement standards at various anatomical points of the mandible (40–42).

Due to its diverse European, African, Asian, and Indigenous origins, the Brazilian population is characterized by a high degree of genetic admixture. Consequently, it is not possible to establish a single, uniform skeletal pattern for this population (15,43,44).

Given this context, all mandibles were analyzed collectively, without stratification by geographic location or presumed ancestry, since the extensive admixture that characterizes the Brazilian population makes it difficult to reliably assign individuals to specific ancestral categories based solely on regional or documentary information. Prior classification into ancestral groups could introduce methodological bias and misclassification error, thereby compromising the internal validity of the study. Furthermore, the use of artificial groupings would not accurately reflect the biological complexity of the analyzed collection, which consists of individuals with varying degrees of shared ancestry. Therefore, the decision to perform a pooled analysis aimed to respect population heterogeneity, enhance the statistical robustness of the proposed model, and generate results that are more consistent with the Brazilian forensic reality, in which reliable ancestry information is often unavailable, requiring methods applicable to a highly admixed population.

There are few documented samples available in Brazil, despite the country's large territorial extent. Therefore, this research was conducted using the sample that was available, and further studies with larger subsamples could better elucidate cut-off points, sensitivity, specificity, and AUC values. Nevertheless, the importance of discussing this issue is substantial and should not discourage research based on the samples available in other parts of the world. Furthermore, for identification purposes in the Brazilian population, it is relevant to include "mixed" data, as this reflects the reality of forensic identification cases. Moreover, the age of the individuals in the sample (older than 18 years) may introduce potential sources of bias, since tooth loss, alveolar resorption, degenerative changes, and bone remodeling are not uniform across this broad age group.

predmeta (38). Alternativa je korištenje CT snimki s obzirom na lakši pristup i činjenicu da fizička analiza uzoraka nije potrebna pa se zbirke i predmeti čuvaju za buduće generacije (23).

Poznato je da se CT snimke mogu koristiti u forenzičke svrhe tijekom identifikacije ljudi. Nakon što se rekonstruiraju u 3D, mogu se procijeniti spol, dob, visina i geografski afinitet, te nužno fizikalne tehnike za pristup nalazima kostiju (2, 39). Literatura prikazuje zdjelicu, lubanju i mandibulu (ovim redoslijedom) kao koštana područja s najboljim rezultatima među onima s najvećim dimorfnim potencijalom (35).

Strukture mentalne protuberance i duljina tijela mandibule ubrajaju se u mjere s najvećim dimorfnim potencijalom, što je jasno iz rezultata dobivenih u ovoj studiji.

Mandibula je, zbog oblika i debljine, među kostima koje se često pronalaze poslije velikih katastrofa i na mjestima zločina. Štoviše, mogu se procijeniti biološke karakteristike osobe metodama koje upotrebljavaju antropometrijske standarde mjerenja na različitim anatomskim točkama mandibule (40 – 42).

Zbog raznolikoga europskog, afričkog, azijskog i autohtonog podrijetla, brazilsku populaciju obilježava visok stupanj genetske primjese. Posljedično, ne može se ustanoviti jedinstveni, ujednačeni skeletni uzorak za tu populaciju (15, 43, 44). S obzirom na to, sve mandibule analizirane su zajedno, bez stratifikacije prema geografskom položaju ili pretpostavljenom podrijetlu, zato što opsežna primjesa koja označuje brazilsku populaciju otežava pouzdano dodjeljivanje pojedinaca specifičnim kategorijama predaka isključivo na temelju regionalnih ili dokumentarnih podataka. Dosadašnja klasifikacija u skupine predaka mogla bi u klasifikaciju unijeti metodološku pristranost i pogrešku, čime bi se ugrozila unutarnja valjanost studije. Nadalje, umjetno grupiranje ne bi točno odražavalo biološku složenost analizirane zbirke koja se sastoji od pojedinaca s različitim stupnjevima zajedničkog podrijetla. Zato se odlukom o provedbi skupne analize nastojalo poštovati heterogenost populacije, poboljšati statističku robusnost predloženog modela i generirati rezultate koji su u skladu s brazilskom forenzičkom stvarnošću u kojoj pouzdane informacije o podrijetlu često nisu dostupne, što zahtijeva metode primjenjive na populaciju s visokom razinom miješanja.

U Brazilu je dostupno malo dokumentiranih uzoraka, iako je zemlja teritorijalno veoma velika. Zato je ovo istraživanje provedeno korištenjem dostupnog uzorka, a u budućim studijama s većim poduzorcima mogle bi se bolje razjasniti granične vrijednosti, osjetljivost, specifičnost i AUC vrijednosti. Ipak, važnost rasprave o tom pitanju znatna je i ne bi trebala obeshrabriti autore istraživanja temeljenih na uzorcima dostupnima u drugim dijelovima svijeta. Nadalje, za potrebe identifikacije u brazilskoj populaciji relevantno je uključiti *mješovite* podatke jer to odražava stvarnost slučajeva forenzičke identifikacije. Štoviše, dob pojedinaca u uzorku (stariji od 18 godina) može biti izvor pristranosti, zato što gubitak zuba, alveolarna resorpcija, degenerativne promjene i preoblikovanje kostiju nisu ujednačeni u toj širokoj dobnoj skupini.

The study by Tunis et al. (30), whose technique we reproduced in the Brazilian sample, used an Israeli population, which has a large biological variability due to immigration to the country, providing a multiracial population with a need for research to study this variability. The study took anthropometric mandible measures, obtaining a total of 25 measures of anatomical points of the mandible, consisting of 13 external and 12 internal measures. All were analyzed through CT images, obtaining concordance rates of up to 90.08% of correctly estimated mandibles in relation to sex.

In contrast, the present study consisted of 12 exclusively external anthropometric measures, aiming to analyze the variability in the results when the internal mandible measures are excluded. The external measurement of the mandibular angle was excluded due to the high rate of intraobserver bias and its lower sexual dimorphic power, as reported by Tunis et al. (30), when analyzing the same measure. The same factor was observed in the present study, and it was decided to exclude this measure.

The cutoff determined in this study showed optimal performance. When analyzing sensitivity and specificity, a positive result was obtained, since the sensitivity percentage ranged from 55.36% to 80.36%, corresponding to the measures of ramus width and condyle width, respectively. Regarding specificity, its percentage ranged from 51.35% to 78.38%, with the measures of coronoid height and condyle width having the lowest percentage, and that of body height p1-p2a and mandibular angle width having the highest percentage of accuracy in estimating sex. The results of this research demonstrate that the measures that correctly estimate sex in the best way are not the same for males and females. The AUC was greater than 0.70 in the following measures: ramus length, body length, height p1-p2a, height m1-m2, mandibular angle width, condyle width, and bigonial width. Hence, these measures obtained statistically acceptable results when estimating sex.

The difficulty in obtaining certain measures in this study is an important factor to be discussed. The chin width is characterized by tactile sensitivity at the time of physical measurement. To achieve greater precision when measuring this width in digital images, incorporating more detailed measurement parameters is essential, as previously demonstrated in a study of modern Black and White South African adults (45).

A comparison with the findings of Tunis et al. (30) reveals that the sex estimation methods yielded a higher accuracy rate in the Israeli population than in the present Brazilian sample. It is worth noting that the present study included a sample of Brazilian individuals, but also mandibles from some South American, North American, European, Asian, and African countries, and Syria, which may be a possible factor for the inferior result. However, other possible reasons can be considered, such as the natural wear of dry mandibles, since the collection has been available for studies for many years.

A study in another Brazilian sample analyzed the volume of the mandibular canal as a parameter for sex estimation, obtaining results of up to 85% agreement (46). A very similar

U studiji Tunisa i suradnika (30), čiju smo tehniku reproducirali na brazilskome uzorku, korištena je izraelska populacija koja ima veliku biološku varijabilnost zbog imigracije u zemlju, pa su u slučaju multirasne populacije potrebna istraživanja kako bi se proučila ta varijabilnost. U studiji su korištene antropometrijske mjere mandibule, dakle, ukupno 25 mjera anatomskih točaka mandibule koje se sastoje od 13 vanjskih i 12 unutarnjih mjera. Sve su analizirane na temelju CT slika, uz stope podudarnosti do 90,08 % točno procijenjenih mandibula kad je riječ o spolu.

Nasuprot tomu, u ovoj studiji primijenjeno je 12 isključivo vanjskih antropometrijskih mjerenja sa svrhom da se analiziraju varijabilnosti rezultata kada se isključe unutarnje mjere mandibule. Vanjsko mjerenje kuta mandibule isključeno je zbog visoke stope pristranosti između promatrača i njegove niže snage spolnoga dimorfizma, kako su izvijestili Tunis i suradnici (30) pri analizi te mjere. Isti čimbenik uočen je i u ovoj studiji te je odlučeno da se ta mjera isključi.

Granična vrijednost određena u ovoj studiji pokazala je optimalne performanse. Tijekom analize osjetljivosti i specifičnosti dobiven je pozitivan rezultat, zato što se postotak osjetljivosti kretao od 55,36 % do 80,36 %, što odgovara mjerama širine ramusa i širine kondila. Kad je riječ o specifičnosti, njezin postotak bio je od 51,35 % do 78,38 %, pri čemu su mjere visine koronoidnoga izrastka i širine kondila imale najniži postotak, a visina tijela p1 – p2a i širina mandibularnoga kuta najveći postotak točnosti u procjeni spola. Rezultati ovog istraživanja pokazuju da mjere kojima se točno procjenjuje spol na najbolji način nisu jednake za muškarce i žene. AUC je bio veći od 0,70 u sljedećim mjerama: duljina ramusa, duljina tijela, visina p1 – p2a, visina m1 – m2, širina mandibularnoga kuta, širina kondila i širina bigonija. Zato su te mjere dale statistički prihvatljive rezultate pri procjeni spola.

Poteškoća u dobivanju određenih mjera važan je čimbenik u ovoj studiji o kojemu treba raspravljati. Širinu brade karakterizira taktilna osjetljivost u trenutku fizičkoga mjerenja. Kako bi se postigla veća preciznost u mjerenju te širine u digitalnim slikama, ključno je uključivanje detaljnijih parametara mjerenja, kao što je već istaknuto u studiji o procjeni modernih odraslih crnaca i bijelaca u Južnoj Africi (45).

Usporedba s nalazima Tunisa i suradnika (30) otkriva da se metodama procjene spola postigla veća stopa točnosti u izraelskoj populaciji nego u ovome brazilskom uzorku. Vrijedi napomenuti da je u tu studiju bio uključen i uzorak brazilskih pojedinaca, ali i mandibule iz nekih južnoameričkih, sjevernoameričkih, europskih, azijskih i afričkih zemalja te Bliskog istoka (Sirije), što bi mogao biti čimbenik za lošiji rezultat. No mogu se uzeti u obzir i drugi razlozi, poput prirodnoga trošenja suhih mandibula zato što je zbirka već godinama dostupna za proučavanje.

Autori studije na drugome brazilskom uzorku analizirali su volumen mandibularnoga kanala kao parametar za procjenu spola i dobili su rezultate do 85 % (46). Vrlo sličan postotak zabilježen je u drugoj studiji u kojoj su korištene suhe CT snimke mandibule u grčkoj populaciji te je točno procijenjeno do 85,7 % uzorka (47). No poznato je da grčki uzorak obuhvaća populaciju s modernim grčkim obilježjima i

percentage was found in another study using dry mandible CT scans in the Greek population, correctly estimating up to 85.7% of the sample (47). However, it is known that the Greek sample comprises a population with modern Greek characteristics and similar geographic origins, which is a positive factor when estimating sex in a sample.

Limitations of this study include the small sample size, wear and fractures of key anatomical landmarks, the inclusion of edentulous mandibles, and a lack of prior data regarding the biological characteristics of the specimens. However, the collection is one of the most important in Brazil, which has limited collections for study. It is recommended that more methods for estimating sex in the Brazilian population be validated, using anthropological parameters, such as the mandible.

Another limitation that should be discussed is the classification documented by the cemetery and included in the records of the ICB-USP Museum. It was used for comparison with the method applied in the present study. Thus, the only reliable documented data available concern skin color, which constitutes a limitation of the study. This topic has sparked debate among authors regarding the terminology used for geographic origin. In a clarifying review on the subject, Cunha & Ubelaker (2019) state that "reports should focus on the likely ancestry of the examined individual or, alternatively, suggesting how this person likely would have characterized himself/herself or have been socially classified by the communities lived in" (48).

The heterogeneity of the sample is consistent with the population variation observed in Brazil, a country of continental dimensions that currently has more than 213 million inhabitants. Studies conducted in Turkey adopted similar sample grouping strategies, since, despite the possible "intra-sample" variation, the data generated have the potential to assist in real forensic identification cases in that country (49, 50).

Consequently, these results should be interpreted with caution. Phenotypic variation must be considered, as numerous factors can influence sexual dimorphism—including biological ancestry or affinity, population-specific robustness, diet, functional loading, dental wear, dentition status, advanced age, post-tooth loss bone remodeling, and secular changes. Further studies are needed to clarify these issues.

In conclusion, the results of this study highlight the importance of investigating distinct populations and utilizing samples from diverse skeletal collections in forensic anthropology. Because studies utilizing CT images of dry mandibles remain scarce in Brazil, expanding this line of research is essential, especially given the vast number of collections available in the country. Digitizing collections is also a relevant topic, and some measures are difficult to perform digitally. Therefore, a booklet with clear guidelines for mandibular measurement in CT images would be useful. Moreover, internal measures of the mandible should be taken together with external ones.

sličnim geografskim podrijetlom, što je pozitivan čimbenik u procjeni spola u uzorku.

Ograničenja ove studije jesu mali uzorak, trošenje i frakture ključnih anatomskih obilježja, uključivanje bezubih mandibula i nedostatak podataka o biološkim karakteristikama uzoraka. No zbirka je jedna od najvažnijih u Brazilu, zemlji koja ima ograničene zbirke za proučavanje. Preporučuje se validacija više metoda za procjenu spola u brazilskoj populaciji i to korištenjem antropoloških parametara, poput mandibule.

Još jedno ograničenje o kojemu treba raspravljati jest klasifikacija koju je dokumentiralo groblje i uključena je u zapise Muzeja ICB-USP. Korištena je za usporedbu s metodom primijenjenom u ovoj studiji. Zato se jedini pouzdani dokumentirani podatci odnose na boju kože, što je ograničenje studije. Ta je tema potaknula raspravu među autorima o terminologiji koja se upotrebljava za geografsko podrijetlo. U objašnjenju o toj temi Cunha i Ubelaker (2019.) navode da bi se *izvješća trebala usredotočiti na vjerojatno podrijetlo ispitivane osobe ili, alternativno, sugerirati kako bi se ta osoba vjerojatno okarakterizirala ili kako bi je društveno klasificirale zajednice u kojima je živjela* (48).

Heterogenost uzorka u skladu je s varijacijama populacije uočenima u Brazilu, zemlji golemih dimenzija koja trenutačno ima više od 213 milijuna stanovnika. Autori studija provedenih u Turskoj prihvatili su slične strategije za grupiranja uzoraka zato što, unatoč mogućim varijacijama *unutar uzorka*, generirani podatci mogu pomoći u stvarnim forenzičkim slučajevima identifikacije u toj zemlji (49, 50).

Slijedom toga, ove rezultate treba tumačiti s oprezom. Fenotipske varijacije moraju se uzeti u obzir jer mnogobrojni čimbenici mogu utjecati na spolni dimorfizam – uključujući biološko podrijetlo ili afinitet, robusnost specifičnu za populaciju, prehranu, funkcionalno opterećenje, trošenje zuba, status denticije, stariju dob, preoblikovanje kostiju poslije gubitka zuba i sekularne promjene. Potrebna su daljnja istraživanja da bi se razjasnila ta pitanja.

Zaključno, rezultati u ovoj studiji pokazuju koliko je važno istraživanje različitih populacija i korištenje uzoraka iz različitih zbirki kostura u forenzičkoj antropologiji. Budući da su studije u kojima se koriste CT snimke suhih mandibula i dalje rijetke u Brazilu, ključno je proširiti taj smjer istraživanja, posebno s obzirom na velik broj zbirki dostupnih u zemlji. Digitalizacija zbirki također je relevantna tema, a neke mjere teško je primijeniti digitalno. Zato bi bila korisna knjižica s jasnim uputama za mjerenje mandibule na CT snimkama. Štoviše, njezine unutarnje mjere treba uzeti zajedno s vanjskima.

## Conclusion

In conclusion, tomographic-based mandibular anthropometric analysis serves as a valuable complementary tool for forensic sex determination, particularly in forensic cases where complete skeletal material is unavailable or fragmented.

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## Zaključak

Zaključno, tomografska antropometrijska analiza mandibule vrijedan je komplementarni alat za forenzičko određivanje spola, posebno kada je potpuni skeletni materijal nedostupan ili fragmentiran.

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**Sažetak**

**Ciljevi:** Istraživao se potencijal mandibule kao anatomske strukture za procjenu spola korištenjem trodimenzionalnih slika generiranih računalnom tomografijom. **Materijali i metode:** Istraživanje je provedeno na 93 suhe mandibule starije od 18 godina iz kolekcije ICB-USP-a, a analiza je obavljena na temelju 12 vanjskih mjerenja provedenih u softveru Meshmixer®. **Rezultati:** Podatci su podvrgnuti binomnoj logističkoj regresiji i analizi ROC krivulje – pritom su otkrivene površine ispod krivulje između 0,61 i 0,76, osjetljivost između 55,36 i 80,36 % i specifičnost između 51,35 i 78,38 %, pri čemu su bili najtočniji duljina ramusa, visina tijela mandibule i širina kuta. U studiji je potvrđeno korištenje tomografije kao alternative izravnoj fizičkoj analizi kostiju, posebno kada je pristup osteološkim uzorcima ograničen. Ističe se važnost validacije metoda u multirasnim populacijama poput brazilske. **Zaključak:** Zaključuje se da je antropometrijska analiza mandibule s pomoću tomografskih slika komplementarni alat u forenzičkoj identifikaciji spola, s praktičnom primjenjivošću kada je teško dobiti kompletan skeletni materijal.

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**MeSH pojmovi:** određivanje spola; donja čeljust
**Autorske ključne riječi:** analiza određivanja spola, forenzička antropologija, mandibula, konusno-snopna kompjutorska tomografija

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