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Comparative Analysis of Nine Morphological Traits in Adult Female Mandibles from China Across Different Eras

Análisis Comparativo de Nueve Rasgos Morfológicos en Mandíbulas de Mujeres Adultas de China a lo Largo de Diferentes Épocas

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SUMMARY: This study examines nine morphological traits of female mandibles from the Holocene period (from over 7,000 years ago to the present). These traits include the heights of the condylar process, the lateral flaring of the mandibular angle, masseteric tuberosity, pterygoid tuberosity, mental spines, bridging of the mylohyoid groove, chin shape, mandibular prognathism, and rocking chair mandibles. Additionally, the study investigates potential temporal variations in these traits. Physical characteristics of the mandibles of 201 Holocene women from China were observed and classified. SPSS 19.0 software was used to calculate prevalence and perform significance tests of differences across periods. Variations were observed across different periods in the heights of the condylar process and the lateral flaring of the mandibular angle. After the Neolithic period, there was a significant decrease in the prominence of the masseteric tuberosity, and the pterygoid tuberosity also showed a marked reduction in the Bronze and Iron Ages compared to the Neolithic period. From the Neolithic to the modern era, the chin shape predominantly exhibited a "round" form, while the proportion of "pointed" chins continuously declined. Unlike the Neolithic and Bronze-Iron Ages, the modern population showed a 0.0 % occurrence of mylohyoid groove bridging, mandibular prognathism, and rocking chair mandibles. Changes in the related traits of the mandible may correlate with a reduction in its size over this period. Some traits might represent specialized manifestations or reflect a certain degree of primitiveness.

KEY WORDS: Mandible; Morphological traits; Temporal variations; Holocene females; Comparative analysis.

INTRODUCTION

The mandible, the movable bone in the skull, functions in concert with the cranium to play a pivotal role in processes such as mastication and phonation, concurrently sustaining a specific facial configuration. Previous research has indicated that the morphological traits of the mandible are correlated with a variety of factors, including the structure of food, masticatory pressures, facial morphology, the dimensions of the middle cranial fossa, the extent of evolutionary changes, historical population dynamics, and climatic conditions (Bastir *et al*., 2004; Puis¸oru *et al*., 2006; Igarashi *et al*., 2008; Fukase & Suwa, 2008). The analysis of mandibular morphology yields crucial insights into research concerning food structure, human evolution, migration patterns, and population relationships (Nicholson & Harvati, 2006).

Extensive research has demonstrated ongoing evolutionary changes in the dimensions of the human mandible during the Holocene. Notably, in Europe, there has been a discernible reduction in mandibular dimensions in recent centuries (Moore *et al*., 1968). In Japan, there has been a significant reduction in both the size and width of the mandible over time, predominantly in regions where masticatory muscles attach, such as the mandibular angle and the coronoid process (Kaifu, 1997). Concurrently, the lateral thickness of the mandibular body has diminished, likely as a concomitant consequence of the overall decrease in size (Kaifu, 2000). In China, both cranial and mandibular bones continue to exhibit signs of micro-evolution during the Holocene (from over 7,000 years ago to the present). These changes are manifested in a reduction in the size of

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the neurocranium and viscerocranium, a narrowing of the nasal aperture, an increase in height and narrowing of the orbital apertures, and a more rounded cranial vault, accompanied by a thinning and diminution of the mandible (Wu *et al*., 2007; Li *et al*., 2012). Additionally, certain morphological traits such as mandibular tori, masseteric tuberosity, and pterygoid tuberosity have also evolved to reflect changes over time (Li & Dai, 2014; Li *et al*., 2018a). Consequently, these studies outline the general characteristics and trends in changes in craniofacial dimensions and morphological traits during the Holocene.

Moreover, specific morphological traits of the mandible correlate with the development of associated masticatory muscles, such as the masseteric tuberosity, pterygoid tuberosity, and genial spines. These structures serve as the attachment or origination points for the masseter, medial pterygoid, and genioglossus muscles, respectively, which are intricately linked to the process of mastication. It is generally hypothesized that the use of tools and changes in food structure during human evolution have reduced the load on masticatory organs, leading to changes in mandibular morphology (Li *et al*., 2012). This study conducts a comparative analysis of nine morphological traits in mandibular specimens from various periods of the Holocene in northern China, aiming to elucidate the manifestation of craniofacial morphology, including that of the mandible, and its variations over time.

MATERIAL AND METHOD

Materials. The study samples consist of 201 female mandibles from the Holocene human population in China, encompassing the period from the Neolithic to modern times. These specimens are categorized based on the era they belong to: 48 from the Neolithic period, 127 from the Bronze and Iron Ages, and 26 from the modern era. Neolithic samples were collected from Yangyuan Jiangjialiang in Hebei, Xishan in Zhengzhou, and Miaozigou in Inner Mongolia. Bronze and Iron Age samples originated from sites such as Lama Cave in Liaoning, Tuchengzi in Inner Mongolia, MinheXiaohan and Mapai in Qinghai, and Longxian in Shaanxi. Modern samples were primarily obtained from populations in Yunnan. Information on the archaeological background of these sites can be found in related literature (Li, 2019). Specimens were selected from the collections housed at the Center for Frontier Archaeology at Jilin University and the Institute of Vertebrate Paleontology and Paleoanthropology at the Chinese Academy of Sciences. Samples from elderly, juvenile, or male individuals, as well as those with ambiguous sexual characteristics, were excluded to control for age-related morphological variation and sexual dimorphism. Ethical approval for this work has been approved by the Biological and Medical Ethics Committee of Minzu University of China (Approval No. ECMUC2021001CO).

Methods. Based on the characteristics observed in the mandible, classification was conducted, followed by statistical analysis of prevalence rates and testing for significant differences in proportions (Z-test method). A result where $|Z|>1.96$ indicates a statistically significant difference, with $p<0.05$ (Zhang & Xu, 2004). Following methods used in related research (Li, 2019), specific observational and classification methods are as follows:

1.2.1 The relative heights of the condylar and coronoid processes are classified into three categories: condylar higher than coronoid (condylar>coronoid), condylar lower than coronoid (condylar<coronoid), and condylar and coronoid heights similar (condylar=coronoid) (Figs. 1A and 2A).

1.2.2 Masseteric tuberosity is classified into three categories: prominent, moderate, and minimal (Figs. 1B and 2A).

1.2.3 The lateral flaring of the mandibular angle is classified into five categories: prominent, moderate, slight, absent, and inward (Figs. 1C and 2B).

1.2.4 Pterygoid tuberosity is also classified into three categories: prominent, moderate, and minimal (Figs. 1D and 2C).

1.2.5 Bridging of the mylohyoid groove is classified into three categories: pronounced (where a distinct mylohyoid bridge spans at least half of the mylohyoid groove), partial (where the bridge spans less than half of the mylohyoid groove), and absent (Figs. 1E and 2D).

1.2.6 Mental spines are classified into three categories: prominent, moderate, and minimal (Figs. 1F and 2E).

1.2.7 Chin shape is classified into three categories: square, pointed, and round (Figs. 1G and 2F).

1.2.8 Mandibular prognathism is classified into four categories based on the degree of anterior protrusion of the mandible: absent, slight, moderate, and pronounced (Figs. 1H and 2G).

1.2.9 Rocking chair mandibles are classified into four categories based on the morphology of the mandibular base: absent, slight, moderate, and pronounced (Figs. 1I and 2H).

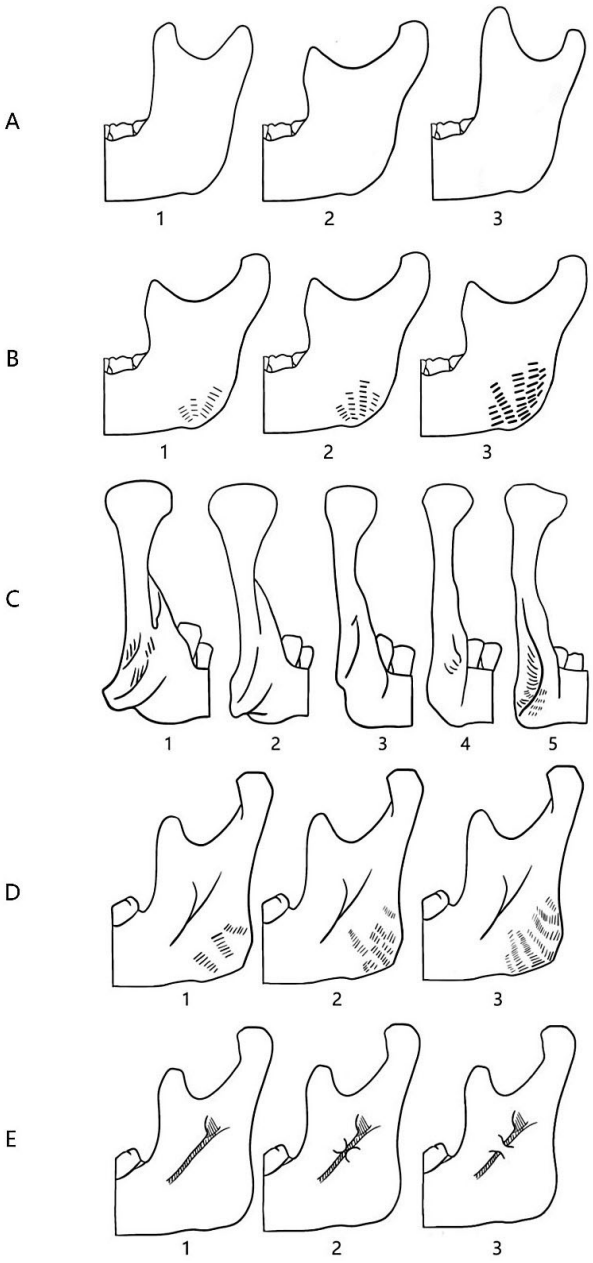

Fig.1. Nine Morphological Traits in Adult Mandibles A) Coronoid Process - Condyle Height Difference A1) Coronoid=Condyle A2) Coronoid<Condyle A3) Coronoid>Condyle B) Masseter Muscle Prominence B1) Weak B2) Moderate B3) Prominent C) Angle of Mandible Flaring C1) Prominent C2) Moderate C3) Weak C4) None C5) Inverted D) Pterygoid Muscle Prominence D1) Weak D2) Moderate D3) Prominent E) Mandibular-Hyoid Groove Bridge E1) None E2) Tendency E3) Present F) Genial Tubercle F1) Weak F2) Moderate F3) Prominent G) Chin Shape G1) Square G2) Round G3) Pointed H) Anterior Mandibular Protrusion H1) None H2) Weak H3) Moderate H4) Prominent I) Rocker Mandible I1) None I2) Weak I3) Moderate I4) Prominent.

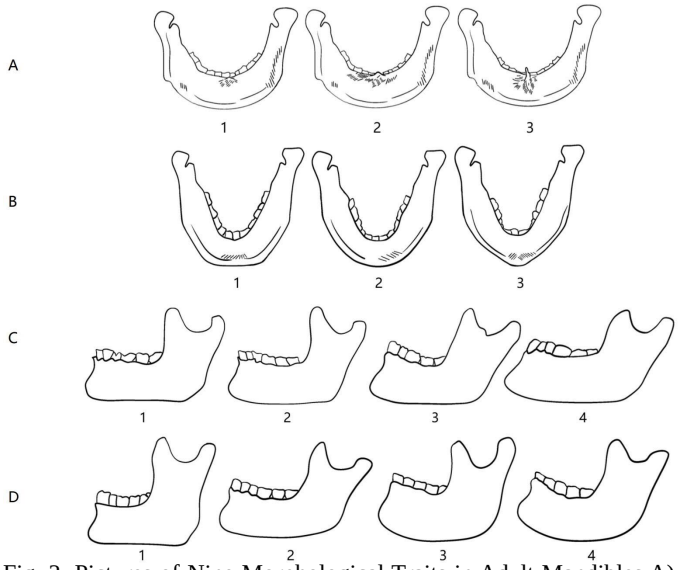

Fig. 2. Pictures of Nine Morphological Traits in Adult Mandibles A) Coronoid Process - Condyle Height Difference and Masseter Muscle Prominence A1) Coronoid=Condyle, Weak A2) Coronoid<Condyle, Moderate A3) Coronoid>Condyle, Prominent B) Angle of Mandible Flaring B1) Prominent B2) Moderate B3) Weak B4) None B5) Inverted C) Pterygoid Muscle Prominence C1) Weak C2) Moderate C3) Prominent D) Mandibular-Hyoid Groove Bridge D1) None D2) Tendency D3) Present E) Genial Tubercle E1) Weak E2) Moderate E3) Prominent F) Chin Shape F1) Square F2) Round F3) Pointed G) Anterior Mandibular Protrusion G1) None G2) Weak G3) Moderate G4) Prominent H) Rocker Mandible H1) None H2) Weak H3) Moderate H4) Prominent.

RESULTS

Comparative Analysis of the Relative Heights of the Condylar and Coronoid Processes Across Different Eras

During the Neolithic period, the predominant characteristic was that the condylar process was lower than the coronoid process (47.7 %). In the Bronze and Iron Ages, the condylar and coronoid processes were generally equal in height (55.0 %). In modern times, the primary characteristic observed was that the condylar process was lower than the coronoid process (61.5 %) (Table I).

Comparative Analysis of the Lateral Flaring of the Mandibular Angle across Different Eras

During the Neolithic era, the lateral flaring of the mandibular angle predominantly exhibited slight flaring (60.9 %) and inward flaring (19.6 %); combined occurrences of moderate to prominent flaring accounted for 10.9 %. In the Bronze and Iron Ages, the most common presentations were slight flaring (50 %) and moderate flaring (25.9 %); moderate to prominent flaring together constituted 34.5 %. In modern times, the predominant characteristics were slight flaring (34.6 %) and

Table I. Comparative analysis of nine morphological traits in female mandibles across different eras.

		Neolithic Period		Bronze and Iron Age		Modern Era		Comparative Analysis		
Characteristics observed	Morphological traits	n	Occurrence (%)	n	Occurrence (%)	n	Occurrence (%)	Neolithic Period - Bronze and Iron Age	Bronze and Iron Age-Modern Era	Neolithic-Modern Era
Relative heights of the condylar and coronoid processes	Condylar process>coronoid process	12	27.3	21	18.9	6	23.1	-1.15	0.48	-0.39
	Condylar process <coronoid process	21	47.7	29	26.1	16	61.5	-2.59*	3.46*	1.12
	Condylar process =coronoid process	11	25.0	61	55.0	4	15.4	3.37*	-3.64*	-0.95
Lateral flaring of the mandibular angle	Prominent	3	6.5	10	8.6	2	7.7	0.44	-0.15	0.19
	Moderate	2	4.4	30	25.9	4	15.4	3.1*	-1.13	1.63
	Slight	28	60.9	58	50.0	9	34.6	-1.25	-1.42	-2.14
	Absence	4	8.7	12	10.3	6	23.1	0.32	1.76	1.69
	Inward	9	19.6	6	5.2	5	19.2	-2.85*	2.42*	-0.03
Masseteric tuberosity	Prominent	12	26.1	7	6.0	2	7.7	-3.58*	0.31	-1.89
	Moderate	14	30.4	30	25.9	4	15.4	-0.59	-1.13	-1.42
	Minimal	20	43.5	79	68.1	20	76.9	2.9*	0.88	2.74*
Pterygoid tuberosity	Prominent	16	33.3	8	7.0	7	26.9	-4.33*	2.98*	-0.57
	Moderate	12	25.0	29	25.2	7	26.9	0.03	0.18	0.18
	Minimal	20	41.7	78	67.8	12	46.2	3.11*	-2.08*	0.37
Mental spines	Prominent	0	0	4	3.2	2	7.7	1.17	1.08	1.82
	Moderate	15	35.7	55	43.7	6	23.1	0.9	-1.95	-1.1
	Minimal	27	64.3	67	53.2	18	69.2	-1.26	1.5	0.42
Bridging of the mylohyoid groove	Pronounced	2	4.6	5	4.1	0	0.0	-0.13	-0.51	-0.53
	Partial	0	0.0	13	10.7	0	0.0	2.26*	-0.84	
	Absent	42	95.5	104	85.3	6	100.0	-1.78	1.01	0.53
Chin shape	Square	8	18.2	4	3.2	5	19.2	-3.35*	3.16*	0.11
	Round	27	61.4	108	85.7	19	73.1	3.44*	-1.58	1
	Pointed	9	20.5	14	11.1	2	7.7	-1.56	-0.52	-1.42
Mandibular prognathism	Pronounced	5	11.4	28	22.4	0	0.0	1.59	-1.31	-0.87
	Moderate	3	6.8	17	13.6	0	0.0	1.2	-0.97	-0.66
	Slight	8	18.2	21	16.8	0	0.0	-0.21	-1.1	-1.14
	Absent	28	63.6	59	47.2	6	100.0	-1.88	2.53*	1.79
Rocking chair mandibles	Pronounced	3	6.8	4	3.3	0	0.0	-1		
	Moderate	1	2.3	6	4.9	0	0.0	0.75		
	Slight	0	0.0	1	0.8	0	0.0			
	Absent	40	90.9	111	91.0	6	100.0	0.01	0.77	0.77

absence of flaring (23.1 %), with moderate to prominent flaring representing 23.1 % (Table I).

Comparative Analysis of Masseteric Tuberosity, Pterygoid Tuberosity, and Mental Spines across Different Eras

During the Neolithic era, the masseteric tuberosity predominantly showed minimal development (43.5 %), with a prominent presence in 26.1 % of cases. In the Bronze and Iron Ages, most masseteric tuberosities were minimal (68.1 %), with only 6.0 % being prominent. In modern times, the prevalence of minimal masseteric tuberosity increased to 76.9 %, while prominent presentations occurred in 7.7 %. There has been a notable decrease in the prominence of masseteric tuberosity since the Neolithic era.

For the pterygoid tuberosity during the Neolithic era, minimal occurrences were reported at 41.7 % and prominent at 33.3 %. In the Bronze and Iron Ages, minimal occurrences rose to 67.8 %, with prominent ones dropping to 7.0 %. In modern times, minimal occurrences were 46.2 % and prominent occurrences increased to 26.9 %. There was a significant decrease in the prominence of pterygoid tuberosity from the Neolithic to the Bronze and Iron Ages.

Regarding mental spines, their minimal occurrences changed as follows: from 64.3 % in the Neolithic era to 53.2 % in the Bronze and Iron Ages, and to 69.2 % in modern times. Moderate occurrences were 35.7 % in the Neolithic era, 43.7 % in the Bronze and Iron Ages, and 23.1 % in modern times. The highest rate of prominent occurrences was in modern times (7.7 %) (Table I). Compared to the Neolithic era, the prominence of mental spines notably increased during the Bronze and Iron Ages.

Comparative Analysis of the Bridging of the Mylohyoid Groove across Different Eras

During the Neolithic era, pronounced bridging of the mylohyoid groove was present in 4.6 % of the population examined, with no instances of partial bridging (0.0 %). In the Bronze and Iron Ages, the occurrence of pronounced bridging remained at 4.1 %, while partial bridging rose to 10.7 %. In modern times, both pronounced and partial bridging of the mylohyoid groove were absent (0 %) (Table I).

Comparative Analysis of Chin Shape, Mandibular Prognathism, and Rocking Chair Mandibles across Different Eras

During the Neolithic era, chin shapes predominantly displayed as round (61.4 %), followed by pointed (20.5 %) and square (18.2 %). During the Bronze and Iron Ages, the prevalent chin shape was round (85.7 %), with pointed shapes accounting for (11.1 %). In contemporary times, round remains the most common chin shape (73.1 %), followed by square (19.2 %). From the Neolithic era to the present, the proportion of pointed chin shapes has been on a declining trend (though not significantly), potentially reflecting corresponding societal changes over these periods.

During the Neolithic era, mandibular prognathism—encompassing slight, moderate, and pronounced cases—was prevalent at a rate of 36.4 %. Moving into the Bronze and Iron Ages, this prevalence increased to 52.8 %, with pronounced cases notably comprising 22.4 % of instances. By contrast, in contemporary times, the occurrence of mandibular prognathism has diminished to an absence of 0.0 %. These observations indicate that mandibular prognathism might be characterized as a potentially primitive anatomical feature.

During the Neolithic era, the prevalence of rocking chair mandibles was 9.1 %, encompassing slight, moderate, and pronounced cases. In the Bronze and Iron Ages, the prevalence remained similar at 9.0 %, however, the incidence of pronounced cases increased to 22.4 %. In the contemporary period, the occurrence of rocking chair mandibles dropped to 0.0 % (Table I). These patterns suggest that rocking chair mandibles might be indicative of a more primitive anatomical trait.

DISCUSSION

Factors Influencing Mandibular Traits

Many characteristics of the mandible are influenced by various factors such as population demographics, muscle development, sex, and food structure, which may affect the expression of specific mandibular traits. The mandible demonstrates relatively significant variability in its traits due to two main reasons: (1) The mandible has a longer growth cycle, exposing it to more external influences during development. Additionally, the mandible provides attachment and support for a greater amount of soft tissue (Masuoka *et al.*, 2005; Hwang *et al.*, 2006); (2) the mandible's high mobility and long-term exposure to diverse mechanical forces contribute to its significant variability.

Generally, males exhibit a greater degree of lateral flaring of the mandibular angle than females (Shao, 1985), a trait linked to the level of muscle development and more pronounced in males (Jabbour *et al.*, 2002). The mylohyoid line of the mandible plays a significant role in differentiating regional types among Mongoloid populations (Shang *et al.*,

2003). Neanderthals, compared to modern humans, display many distinct mandibular features, such as a higher coronoid process relative to the condylar process (Jabbour *et al*., 2002).

Temporal Variations and Causes in Mandibular Traits among Chinese Women

Over the past 7,000 years, the female mandible within the Holocene population of China has continued to evolve. From the Neolithic era through the Bronze and Iron Ages to contemporary times, there has been a marked trend toward a reduction in mandibular size. The primary thinning of the mandibular body mainly occurred from the Neolithic to the Bronze and Iron Ages. Significant reductions in both the overall size and the height of the mandible primarily took place from the Bronze and Iron Ages to the present. The evolutionary trajectory of the mandible is characterized by an initial reduction in thickness, followed by a decrease in overall size (Li *et al*., 2018b). These changes in size may also influence the variability of certain observable mandibular traits.

From the Neolithic to the Bronze and Iron Ages, the increased degree of lateral flaring of the mandibular angle may be related to changes in the mandible's size during this period. This could represent accompanying or compensatory changes due to the reduction in mandibular body height, thinning of the mandibular body, and narrowing of the mandibular ramus.

From the Neolithic to modern times, the weakening of the masseteric tuberosity might reflect a reduction in the masticatory muscles during the Holocene. The pterygoid tuberosity exhibited weakening from the Neolithic to the Bronze and Iron Ages and was strengthened from the Bronze and Iron Ages to modern times. Compared to the Neolithic era, the mental spines in the Bronze and Iron Ages were significantly strengthened.

From the Neolithic to modern times, the proportion of square chin shapes initially decreased significantly, then increased significantly again. The reduction in mandibular thickness from the Neolithic to the Bronze and Iron Ages may have also led to a weakening of the mental tubercles, potentially explaining the significant decrease in the proportion of square chin shapes during this period. From the Bronze and Iron Ages to modern times, the menton became more "pronounced," with many mental triangles appearing as inverted "T" shapes, leading to a flattening of the anterior lower edge of the mandibular symphysis, which might be the primary reason for the increase in square chin shapes (Li, 2012).

Mandibular prognathism (pronounced) exhibited a higher prevalence during the Bronze and Iron Ages, with a prevalence of 0 % in modern human mandibles. The prevalence of rocking chair mandibles consistently decreased from the Neolithic era to the Bronze and Iron Ages, and was entirely absent in modern times. The absence of mandibular prognathism and rocking chair mandibles in contemporary populations might indicate the unique or relatively primitive nature of these traits, possibly reflecting the microevolutionary characteristics of the mandible.

Limitations of This Study

This study has delineated the characteristics of nine morphological traits of the mandible throughout the Holocene, striving to elucidate their temporal variations and underlying causes. These insights are invaluable for research into modern human skeletal anatomy and the study of fossilized mandibular traits. Nevertheless, this investigation is subject to several limitations:

Data Integrity Concerns: The data on the bridging of the mylohyoid groove might be skewed. Given the thin and brittle nature of this trait, it is possible that some specimens were damaged during post-excavation cleaning processes.

Ambiguity in Trait Classification: The categorization of some traits proved ambiguous, a persistent challenge in the classification methodology of trait observation that is tough to completely resolve.

Methodological Constraints: Discussions on chin shapes were confined to traditional classification approaches, although these traits could potentially be more accurately depicted using geometric morphometric methods.

Not Many in Quantity of Relevant Literature: There are not many comprehensive studies in quantity on certain traits, such as mandibular prognathism and rocking chair mandibles. This study only conducted a preliminary exploration of these topics. It is conjectured that biomechanical experiments could yield a more nuanced understanding of the causes behind these variations, with plans for more in-depth studies in the future.

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WANG, L.; CHEN, H.; ZHANG, P.; WAILI, A.; XIANG, Y.; ZHANG, X. & LI, H. Análisis comparativo de nueve rasgos morfológicos en mandíbulas de mujeres adultas de China a lo largo de diferentes épocas. *Int. J. Morphol., 43(5)*:1596-1602, 2025.

RESUMEN: Este estudio examinó nueve rasgos morfológicos de mandíbulas femeninas del Holoceno (desde hace más de 7000 años hasta la actualidad). Estos rasgos incluyen la altura del proceso condilar, el ensanchamiento lateral del ángulo mandibular, la tuberosidad maseterina, la tuberosidad pterigoidea, las espinas mentonianas, el puente del surco milohioideo, la forma del mentón, el prognatismo mandibular y las mandíbulas en silla mecedora. Además, el estudio investiga las posibles variaciones temporales en estos rasgos. Se observaron y clasificaron las características físicas de las mandíbulas de 201 mujeres chinas del Holoceno. Se utilizó el programa SPSS 19.0 para calcular la prevalencia y realizar pruebas de significancia de las diferencias entre períodos. Se observaron variaciones entre diferentes períodos en la altura del proceso condilar y el ensanchamiento lateral del ángulo mandibular. Después del Neolítico, se observó una disminución significativa en la prominencia de la tuberosidad maseterina, y la tuberosidad pterigoidea también mostró una marcada reducción en las Edades del Bronce y del Hierro en comparación con el Neolítico. Desde el Neolítico hasta la era moderna, la forma del mentón fue predominantemente redonda, mientras que la proporción de mentones puntiagudos disminuyó continuamente. A diferencia del Neolítico y la Edad del Bronce y del Hierro, la población moderna mostró una incidencia del 0,0 % de puentes del surco milohioideo, prognatismo mandibular y mandíbulas en silla de balancín. Los cambios en los rasgos relacionados de la mandíbula podrían correlacionarse con una reducción de su tamaño durante este período. Algunos rasgos podrían representar manifestaciones especializadas o reflejar cierto grado de primitivismo.

PALABRAS CLAVE: Mandíbula; Rasgos morfológicos; Variaciones temporales; Mujeres del Holoceno; Análisis comparativo.

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