Is there enough evidence so that mandible can be used as a tool for sex dimorphism? A systematic review

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Abstract
Statement of Problem: One of the most challenging tasks for forensic science is to identify the unknown human skeletal remains of deceased individuals. Study of sex by distinguishing the various morphological characteristics of bones is utmost important in forensic anthropology and for medico-legal assessment. Purpose: The purpose of this article is to review the literature, to find if there is sufficient evidence to establish the use of mandible in sex identification. Materials and Methods: An electronic search was performed to identify suitable literature, using database of MEDLINE, PubMed, and EBSCOhost. Published articles in between January 2000 and April 2015 were searched. The main focus of search was on the various parameters of mandible studied in last 15 years for sex dimorphism. The focus was on the articles published on radiographic studies as well as on morphometric studies of dry mandible in which skeletal parameters were studied. The screening of titles and abstracts were done, suitable literature that fulfilled the inclusion criteria was selected for a full-text reading. Results: The initial literature search resulted in 89 articles, out of which only 36 articles fulfilled the inclusion criteria and were included in this systematic review. Conclusion: Out of 16 radiographic studies, 14 showed statistically significant results that the adult mandible could be used with increased sensitivity and objectivity to identify both sex and population affinity compared to other standard analytical techniques, whereas two studies showed insignificant results. Out of 20 morphometric studies of dry mandible 15 studies showed a positive correlation between sex dimorphism and mandibular parameters and five studies did not show any positive correlations between the two.

Key words: Anthropology, dry mandible, flexure, osteologic, radiographic, sex dimorphism

Introduction
The aim of osteology is to establish the attributes for an individual from their skeletal remains. In anthropological, archaeological, and forensic studies along with the ethnicity and stature, age determination, the identification of sex from human skeletal remains is an

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important element. The pelvis is the most reliable source for sex dimorphism among human bones, but when a complete pelvis is absent in such cases, other bones such as mandible can be an important aid in identification. Since mandible retains its shape better than other bones and as it is most durable facial bone, it is appropriate for study. Many researchers claim a sexing accuracy of 80% from the cranium alone, 90% from the skull and mandible, and 98% from the pelvis. This review of literature is an attempt to summarize the morphometric parameters of dry mandible and radiographic parameters of mandibular bone, which can be used for sex dimorphism and to find out whether mandible can be used successfully as a tool for sex dimorphism?

Search strategy
A broad search of the literature in MEDLINE, PubMed, and EBSCOhost database was performed for articles published between January 2000 and April 2015. A focus was made on peer-reviewed journals. The key words searched were anthropology, dry mandible, flexure, sex dimorphism, radiographic, osteologic, morphometric. The search strategy included the combination of the following terms: “Mandible and sex dimorphism; radiograph in mandible sex dimorphism; osteologic studies, dry mandible and sex dimorphism; ramus in sex differentiation; mental foramen in sex differentiation, morphometric study of dry mandible.” Manual searches of the references of all full-text articles and relevant review articles selected from the electronic search were also performed.

Selection criteria
To determine the studies to be included in this systematic review, the following inclusion criteria were decided. Articles related to mandible in sex dimorphism were only included. Only original articles were included. Both abstract and full text articles were included. Review articles and case reports were excluded. On articles with both maxilla and mandible parameters in sex dimorphism, only mandibular parameters were included. Studies that did not meet any of the inclusion criteria were excluded from the review. The literature search initially resulted in 89 articles out of which only 36 articles fulfilled the inclusion criteria and were included in this systematic review. A systematic review of available articles from the MEDLINE and PubMed on morphometric studies of dry mandible and radiologic studies was done. A synopsis of various radiographic studies on mandible in sex dimorphism was presented in Table 1. And synopsis of skeletal parameters of morphometric studies on dry mandible in sex dimorphism was presented in Table 2.

Results
Most of the studies reviewed showed statistically significant sex differentiations. Among the most prominent parameters showing sex dimorphism was the ramus of the mandible showing demarcating measurements in ramus breadth and ramus height. Other major parameters which showed statistically significant sex dimorphism were the bicondylar and bigonial width, position of the mental foramen, mandibular length, and chin height. Mandibular ramus flexure was one parameter which has been studied extensively but showed inconsistent results. Very few studies were available on factors such as condylar length and breadth, gonial angle, symphyseal height, and fossa inclinations, but those available showed higher values for males.

Discussion
This article reviewed the various parameters of mandible studied in last 15 years for sex dimorphism. Most of the studies done showed statistically significant sex demarcations. Among the most prominent parameters showing significant sex dimorphism was the ramus of the mandible which showed differences in minimum ramus breadth and height. In the study by Ongkana and Sudwan on Thai population minimum ramus breadth for male and females was 32.8 mm and 31.4 mm, respectively. In another study by Pokhrel and Bhatnagar in Indian population, the ramus breadth values were 36.59 ± 6.01 and 28.71 ± 2.72 for male and female, respectively. Kharoshah et al. also studied that the predictive accuracy for sex difference was 83.6% in males and 84.2% in females in Egyptian population using minimum ramus height as a factor. Using ramus height as study parameter in Jordanian population Al-Shamout et al. concluded that the difference was statistically significant with right side values being 54.02 mm in males and 49.77 mm in females and the left side values for male, i.e., 52.62 mm in relation to females i.e. 48.44 mm. In another study using ramus height on Indian population, Thakur et al. also concluded that ramus height can be successfully used as a tool for sex dimorphism with higher values for males. The right side values for male and female were 53 mm and 45.8 mm, respectively, and the left side values were 59.4 mm for male and 36.5 mm for female, respectively. The measured values for both the parameters were higher for male irrespective of the populations studied by many researchers.

Though ramus flexure has been widely studied it showed inconsistent results mainly due to improper grading system. Coqueugniot et al. and Saini et al. concluded that ramus flexure can be successfully used to determine sex with an high average accuracy of up to 82%, while Hill conclude that the results were not consistent as 79.1% accuracy was seen in first evaluation and only 64.7% of the scores were duplicated in the second session. Kemkes-Grottenthaler et al. concluded an overall accuracy of 59%.
Table 1: Summary of various radiographic studies on mandible in sex dimorphism

| Author          | Year | Population          | Number of subjects (male/female) | Group age (mean), years | Parameters for study                                      | Study design                          | Observation (mm) | Conclusion                                                                 |
|-----------------|------|---------------------|----------------------------------|-------------------------|---------------------------------------------------------|--------------------------------------|------------------|---------------------------------------------------------------------------|
| Saglam[4]       | 2002 | Turkish Dentate and edentulous group both (48, 48) | Dentate group=43-68 Edentulous group=43-83 | Mandibular vertical measurements at three locations | Panoramic radiographs | The distance from the lower border of the mandibular to other locations were significantly greater in men in both the groups when compared to women | After tooth loss there was differences in alveolar ridge resorption between the sexes |
| Rai[5]          | 2007 | Indian 103 (51/52)  | 55-76                            | Mandibular vertical measurements at four locations | Orthopantomography | Significant difference was seen in the distance between the superior margin of mental foramina to crest of the alveolar ridge | This distance decreases significantly with age, and rapidly in females  |
| Galdames et al.[6] | 2008 | Chilean 188 (80/108) | Average age of 21.13 years        | Mandibular ramus flexure | Orthopantomograph | Females were 63.25% (62-64.5%) correctly sexed, whereas the prediction accuracy was only 48.25% (46.5-50%) for men | Results were better for the diagnosis of sex in females than in males |
| Kharoshah et al.[7] | 2010 | Egyptian 330 (165/165) |                                      | Six mandibular parameters were evaluated | Spiral CT scan | Statistically significant sex differences were seen in bicondylar breadth, gonial angle, and minimum ramus breadth | The overall predictive accuracy of this study was 83.6% in males and 84.2% in females |
| Kalinowski and Rózylo-Kalinowska[8] | 2011 | Polish 877 (410/467) | 20-95 (48.69) Mandibular height in the mental foramen region | Mandibular height in the mental foramen region | Digital panoramic radiograph | Mean height of the mandible on the right side was greater in males than in females | The differences for both parameters were statistically significant |
| Rashid and Ali[9] | 2011 | Iraqi 300 (150/150) | 20-49                            | Four vertical measurements of mental and mandibular foramina | Digital panoramic radiography | Males almost have higher measurements than females | Statistically significant differences were observed in all linear measurements between sexes |
| Angel et al.[10] | 2011 | 165 (55/110)  | 18-80                            | Location of inferior alveolar canal was assessed at three points | CBCT | The relative location of the inferior alveolar canal and associated foramina in adults remain fairly constant without regard to age and sex | The results were not statistical significant at (P<0.05) |

Contd...
| Author                  | Year | Population     | Number of subjects (male/female) | Group age (mean), years | Parameters for study                                                                 | Study design                          | Observation (mm)                     | Conclusion                                                                 |
|------------------------|------|----------------|----------------------------------|-------------------------|--------------------------------------------------------------------------------------|---------------------------------------|--------------------------------------|--------------------------------------------------------------------------------|
| Wu et al. [11]         | 2012 | Asian          | 198 (103/95)                     | Female=11-88 Male=15-98 | Mandibular fossa inclination was studied at different points                           | Computed tomography (sagittal view) | LA, LP and RA                        | Male=41.7±8.9; 36.4±7.3; 41.2±8.7 Female=36.8±7.8; 34.1±6.6; 37.0±7.4 (degrees) |
| Sheikhi et al. [12]    | 2012 | Isfahan        | 102 (57/55)                      | 21-91 (52.37)           | Locations, sizes, and length of LF were assessed                                     | CBCT                                  | Males had significantly larger distance between buccal end of lingual canal from inferior and buccal plate |
| Felicita et al. [13]   | 2012 | South Indian   | 120 (60/60)                      | 17-28                   | Subspinale supramentale, superior and inferior prosthion                              | Lateral cephalograms                  | Significant difference of maxillary length at subspinale and superior prosthion and mandibular length at supramentale and inferior prosthion |
| Al-Shamout et al. [14] | 2012 | Jordanian      | 209 (103/106)                   | 11-69 (33.51±14.5)     | Ramus height Bigonal width Mandibular gonial angle                                   | Digital panoramic radiography         | Male subjects had higher values Sex differences in gonial angle were not statistically significant |
| Chole et al. [15]      | 2013 | Indian         | 1060                             | 15-66                   | Gonial angle, antegonial angle and antegonial depth                                  | Panoramic radiographs                | Males had smaller gonial angle and antegonial angle and greater antegonial depth than females |
| Chandra et al. [16]    | 2014 | North Indians  | 100 (60/40)                      | 18-62                   | Perpendicular distance from superior and inferior borders of mental foramen to lower border of the mandibular | Orthopantomograph                    | Tangents were made from superior (S-L) and inferior borders of the foramen (I-L), perpendiculars were drawn from the tangents to the lower border of the mandible |
| Thakur et al. [17]     | 2014 | South India    | 102 three groups each of 34 radiographs | Three groups <25 25-50 >50 | Four parameters were studied                                                         | Digital orthopantomograph (right side) | Significant difference obtained between all the four parameters |

Contd...
Table 1: Contd....

| Author           | Year | Population       | Number of subjects (male/female) | Group age (mean), years | Parameters for study | Study design | Observation (mm) | Conclusion                                      |
|------------------|------|------------------|----------------------------------|-------------------------|----------------------|--------------|------------------|------------------------------------------------|
| Genú et al.      | 2014 | Brazilian        | 142 (43.4%/56.6%)               | 21-79 (49.84)           | MF AL IC             | CBCT         |                  | One MF was found on each side in all subjects  |
|                  |      |                  |                                  |                         |                      |              |                  | AL was seen in 18.9% of the images              |
|                  |      |                  |                                  |                         |                      |              |                  | In 96.5% of the images it was possible          |
|                  |      |                  |                                  |                         |                      |              |                  | to identify the anterior extension of the IC   |
|                  |      |                  |                                  |                         |                      |              |                  | No significant difference (P>0.05) between sex |
|                  |      |                  |                                  |                         |                      |              |                  | was observed                                      |
| Indira et al.    | 2015 | Indian           | 100 (50/50)                     | 21-79 (49.84)           | MF AL IC             | CBCT         |                  | Each variable was a significant predictor in    |
|                  |      |                  |                                  |                         |                      |              |                  | classifying a given sample (P<0.001)           |
|                  |      |                  |                                  |                         |                      |              |                  | The mean values showed that all dimensions      |
|                  |      |                  |                                  |                         |                      |              |                  | were higher in males compared to females        |

MF: Mental foramen, AL: Anterior loop, IC: Incisive canal, LF: Lingual foramen, CBCT: Cone-beam computed tomography, LA: Left anterior, LP: Left posterior, RA: Right anterior

Table 2: Synopsis of skeletal parameters of morphometric studies of dry mandible in sex dimorphism

| Author                     | Year | Population       | Number of subjects (male/female) | Group age (mean), years | Parameter for study | Study design | Observation (mm) | Conclusion                                      |
|----------------------------|------|------------------|----------------------------------|-------------------------|----------------------|--------------|------------------|------------------------------------------------|
| Coqueugniot et al.         | 2000 | Palaeolithic     | 06 Homo sapiens fossil           | Late adolescence and adulthood | MRPF                 | Visual skeletal study | Score of 0 to +2 was identified as males, and −1 or −2 was identified as females | A visual assessment of MRPF as a sex indicator did not bring any high significant value |
| Hill                       | 2000 |                  | 158                              |                          | Mandibular ramus flexure | Visual skeletal study | 79.1% accuracy was seen in first evaluation and only 64.7% in second | Low overall accuracy in sex dimorphism         |
| Loth and Henneberg         | 2001 | South African    | 62 0-19                           |                          | Symphyseal base and body shape | Mandible | Symphyseal base and body shape in male and female were compared | Males were consistently identified more accurately than females |
| Kemkes-Grottenthaler et al.| 2002 | whites and blacks| 153                              |                          | Mandibular ramus flexure and gonial eversion | Mandible | Ramus flexure Male=66% Female=32% Gonial eversion Male=75.4% Female=5.2% | Low accuracy for both the parameters due to age and localized tooth loss |
| Hu et al.                  | 2006 | Korean           | 102                              |                          | 13 nonmetric items    | Morphological characteristics | Rocker shaped mandibles, bilobate or square chin predominated in males | Nonmetric parameters could be used for sex dimorphism |
| Franklin et al.            | 2007 | African American | African American (18/19)            |                          | Bilateral points and midline points of mandible | Subadult mandible Morphometric study | No significant sexual dimorphism in the subadult sample | The subadult mandible is not dimorphic |

Contd...
| Author                  | Year | Population          | Number of subjects (male/female) | Group age (mean), years | Parameter for study | Study design | Observation (mm) | Conclusion                                                                 |
|-------------------------|------|---------------------|---------------------------------|--------------------------|--------------------|--------------|------------------|-----------------------------------------------------------------------------|
| Ongkana and Sudwan      | 2009 | Thai population     | 102 (68/34)                     | Male/female=67.35±12.0 /63.35±13.52 | Nine parameters    | Dried mandible | Metric analysis   | Eight out of nine parameters (except chin height) showed significant difference |
| Galdames et al.         | 2009 | Brazilian           | 32 (20/12)                      | 0-1                      | Eight mandibular parameters | Dried mandible | Most of the dimensions were higher in male                                |
| Saini et al.            | 2011 | Indian              | 112 (88/24)                     |                          | Mandibular ramus flexure | Dried Mandible |                  | This trait can be used to diagnose gender with an average accuracy of up to 82%   |
| Carvalho et al.         | 2013 | Brazilian population| 66 (34/32)                      | Older than 20 years      | Bigonial distance and mandibular ramus height | Anthropology (skulls) | Accuracy of 76.47% for males and 78.13% for females | Parameters and methodology must be validated for the different groups |
| Marinescu et al.        | 2013 | Romanian            | 200 (100/100)                   | 20-86 (39)               | Chin height, bigonial width and bicondylar breadth | Adult dried mandible | The accuracy of discriminant function using all 3 variables is 84%, equal for male and female |
| Vinay et al.            | 2013 | South Indian        | 250 (175/75)                    | 0-65                     | Bigonial breadth and bicondylar breadth | Metric analysis of mandible | Male=75.92, 71.39, 66.02%, Female=71.16, 63.54, 53.01%, respectively | Bipogonial width provided 80.5% accuracy, slightly better for males |
| Kumar and Lokanadham    | 2013 | South India         | 80                              | 18-60                    | 22 parameters of mandible were evaluated | Dried mandible | Symphyseal height, body thickness, body length, anthropometric arch width, mandibular angle, bicondylar diameter | Mandible of unknown sex can be sexed to the extent of 75% accuracy by six dominating parameters |
| Thakur et al.           | 2013 | Indian              | 60 (30/30)                      |                          | Mandibular angle and height of the ramus | Dried mandible | Using mandibulometer | Significant difference obtained between males and females |
| Pokhrel and Bhatnagar   | 2013 | Pune (India)        | 158 rami from 79 intact mandibles |                          | Minimum and maximum ramus breadth, maximum condylar length and breadth | Dried mandible | Measurements taken from rami and condyle were greater for males | All the values were greater for males, then for females |
| Raj and Sindhu          | 2013 | South Indian        | 120 (60/60)                     |                          | Four mandibular parameters were evaluated | Adult mandible | Digital Vernier caliper | The ramus part of mandible has satisfactory potential for determination of sex |
| Kranoti et al.          | 2014 | Greek               | 70 (36/34)                      | >66 (55.3±8.8 /50.9±15.8) | Chin height, minimum ramus height, bicondylar, bigonial and bimalental breadth | Dried mandible |                  | Bigonial breadth is most discriminatory factor with accuracy of 71% followed by bicondylar breadth with (69%) |

Contd...
Table 2: Contd....

| Author          | Year | Population | Number of subjects (male/female) | Group age (mean), years | Parameter for study | Study design | Observation (mm) | Conclusion                                               |
|-----------------|------|------------|----------------------------------|-------------------------|---------------------|--------------|-------------------|---------------------------------------------------------|
| Akhlaghi et al. | 2014 | Iranian    | 45 (23/22)                       | Below the age of 20     | Eight mandibular anthropometric parameters | Cadavers     | No significant statistical difference was seen in the values between the two sexes in samples below the age of 12 | Symphyseal height and mandibular bigonial breadth could be used to determine the sex |
| Lin et al.      | 2014 | Koreans    | 240 (120/120) Mean age 46.2      | 11 parameters           | Discrimination function analysis using 3D mandible models | Mandibular flexure upper border, maximum ramus vertical height and upper ramus vertical height expressed the greatest dimorphism | Upper ramus above flexure holds larger potential than the mandibular ramus flexure itself to predict sexes |
| Pillai et al.   | 2014 | South India| 88                               | 18-60                   | Mandibular morphology was studied for 22 parameters | Dried mandible | Significant differences obtained in height of the ramus, body thickness, mandibular angle etc. | Six dominating characteristics could possibly help in identification of sex |

P value: Prevalence, MF: Mental foramen, 3D: Three-dimensional, MRPF: Mandibular ramus posterior flexure

Other parameter showing consistently significant higher values for male was the bicondylar width. In the study by Ongkana and Sudwan[1] on Thai population bicondylar width for male was 123.8 mm and for females was found to be 116.1 mm. Marinescu et al.[29] also concluded similar results in Romanian population with males showing higher values, i.e., 120 mm and 113.1 mm for females. Similarly, Vinay et al.[30] in his study on Indian population showed similar results with male values of 129 mm and 96.9 mm for females, and Kranioti et al.[2] showed male values of 118.72 mm and 113.34 mm in females for Greek population, respectively. These results were further supported by the study of Kumar and Lokanadham[31] on Indian population who concluded the bicondylar diameters to be in range of 91–126 mm.

Bigonial breadth can also be considered as a statistically significant factor for sex dimorphism. In the study conducted by Vinay et al.[30] on Indian Population, the measured values were 103.5 mm for males and 78 mm for females, which were supported by the findings of Kranioti et al.[2] who found the male measurements to be 101.169 mm and female measurements to be 93.974 mm in Greek population.

A large number of studies were conducted on the position of the mental foramen. Rai[5] studied the Indian population and concluded that a statistically significant sex difference existed between the superior margins of mental foramina to crest of the alveolar ridge. These finding were further supported by the study conducted by Rashid and Ali[9] where the distance was 17.4 ± 0.119 mm for males and 16.01 ± 0.121 mm for females in Iraqi population. Thakur et al.[17] also studied the same parameter and found the distance to be statistically more in males and concluded that the distance between the superior margins of mental foramina to crest of the alveolar ridge can be used as a tool for sex dimorphism with high accuracy. The distance between the inferior margins of the mental foramen to the inferior border of the mandible also showed a high accuracy for sex dimorphism.[8,9,16,17] Chandra et al.[16] found the lower height to be 12.67 mm in males and 11.46 mm in females on the right side and 12.58 mm in males and 11.25 mm in females on the left side in Indian. Rashid and Ali[9] found these measurements to be 10.06 ± 0.101 mm in males and 9.24 ± 0.095 mm in female which coincided with other similar studies.

Mandibular length and chin height were also evaluated, and measurements were higher for males in all studies.[1,30] Ongkana and Sudwan[1] found the mandibular length to be 8.94 mm in males and 8.53 mm in females of Thai origin. Similar values were reported by Vinay et al.[30] in Indian population who found the male measurements to be 8.81 mm and female measurements to be 6.22 mm for mandibular length. Chin height values were 29.78 for males and 26.12 for females in the study conducted by Kranioti et al.[2] and 32.1 mm and 29.4 mm in the study conducted by Marinescu et al.[29] in Romanian population for males and females respectively.
Conclusion

The present review revealed that there was a statistically significant sex dimorphism in mandible. 87.5% of radiographic studies showed statistically significant results that the adult mandible could be used to identify both sex and population affinity compared to other standard analytical techniques. Out of twenty morphometric studies of dry mandible 75% of studies showed a positive correlation between sex dimorphism and mandibular parameters. The review further concludes that it is better to use more number of variables than single parameters for higher accuracy in identification of the mandible in sex differentiation. Growing mandible cannot be used as a very accurate method in sex differentiation as its studies showed a lower rate of sex differentiation than adult bone. Hence, due to the differences in ethnic patterns parameters and methodology must be validated and standardized for the different groups of population.

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There are no conflicts of interest

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