A Validation Study of the Mandibular Canine Index Method of Sexual Assessment Using Two Decedent American Populations

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Abstract

Rao and colleagues (1989) created the Mandibular Canine Index (MCI) as a method of sex assessment. It has primarily been used on living South Asian populations. This study applies the MCI to two U.S. skeletal collections to determine its potential as a sexing method in forensic anthropology. Forty-five individuals from the C.A. Pound Human Identification Lab and the Wichita State Biological Anthropology Lab with full mandibular dentition were studied. The mesio-distal width of both right and left canines and the canine arch width were taken and the MCI calculated along with the standard MCI. Results show that the MCI was not significantly different between males and females (p=.46 for right and p=.47 for left). The standard MCI was .24 for the right and .20 for the left. This gave an accuracy of 37–44% for males and 44–45% for females, worse than chance. However, the mesio-distal length (p=.002 for right and .001 for left) and canine arch width (p=.019) on their own were significantly different between males and females and have utility in sex assessment, although they have high error rates. Further study should be done with a larger sample size to see if results are consistent.

Keywords: *Mandibular Canine Index; Sex Assessment; Dentition; Canines*

Introduction

Sex assessment is an important part of the biological profile that can be used to narrow down or to exclude the identity of an unidentified skeleton. Postcranial elements have been determined to be more reliable for sex assessment than the skull using metric based methods (Spradley & Jantz, 2011), however, it is not unusual for forensic anthropologists to analyze cases where only the skull or even just a mandible is present. With limited elements for estimating sex, anthropologists are continually researching new techniques that may be more accurate than current sex assessment methods. Studies have found that teeth are sexually dimorphic in humans, although less pronounced than in other primates, such as baboons, in which canines can exhibit 70% or more dimorphism. Great apes show between 40% to 20% canine dimorphism. Human dental dimorphism is about 2–6%, with mandibular canines being the most dimorphic at 6%, although it can vary depending on the population. In general males have larger canines than females, making them potentially valuable in research pertaining to sex assessment (Acharya & Mainali, 2007; Hillson, 1996). The higher sexual dimorphism of the canines has been suggested to be due to the fact that the canines functioned evolutionarily as a signal of male dominance that may be a holdover from our hominin ancestors, as other great apes also share this feature except to a greater extreme (Anderson & Thompson, 1973).

Studies have found that the accuracy of tooth measurements in classifying individual's sex is between 60–90% (Hillson, 1996). Since canines are the most sexually dimorphic tooth, some researchers have examined the accuracy of several canine measurements such as the

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mesio-distal length and canine arch width for sex assessment. Rao and colleagues' (1989) study focused on sex assessment using the canines and examined mandibular canine measurements in a living South Indian population. The authors created a ratio called the mandibular canine index (MCI; see below). From the MCI, a standard MCI formula was computed using the mean MCI for both sexes, providing a sectioning point value for predicting sex. Rao et al. (1989) found that males had significantly higher mandibular canine indices than females with accuracy of 84.3% for males and 87.5% for females using the standard MCI. Their error rate is 24.5%.

Since the Rao article was published, the majority of studies have also focused on populations from India (Duraiswamy et al., 2009; Kaushal et al., 2004; Narang et al., 2014; Rathi et al., 2019; Reddy et al., 2008; Signh et al., 2019; Vijayan et al., 2019; Vishwakerma & Guha, 2011; Yadav et al., 2002). Muller et al. (2001) was one of the first studies to look at populations outside of India. They validated the MCI on a population from Nice, France and concluded that correct tooth alignment within the alveolus is important and that a standard MCI needed to be calculated for each population. More recently, standard MCI has also been calculated for Nigerian populations (Nuhu et al., 2019; Otuahn et al., 2019), Pakistani populations (Hassan & Meman, 2018; Hussain et al., 2012; Shahid et al., 2018), Nepali populations (Acharya & Mainali, 2007, 2009; Bajracharya et al., 2018;), a Chinese population (Iqbal et al., 2015); a Bosnian population (Muhanedagic & Sarjic, 2013), a Brazilian population (Sassi et al.,2012), an Iraqi population (Ahmed et al., 2014) and a British population (Hussain et al., 2012; **Table 1**). A meta-analysis performed in 2018 found at least 26 studies utilizing the MCI between 2000 and 2016 (Dony et al., 2018).

These MCI studies all used living individuals, most of which were approximately 17–25 years in age and attending university. A few studies looked at younger or older populations, but none younger than 14 years or older than 45 years (Duraiswamy et al., 2009; Signh et al., 2019). These studies used either dental casts of the individual's dental arch or took intraoral measurements. There were no significant differences in results based on how the measurements were taken (Kaushal et al., 2003; Patel et al., 2017).

Many of these studies have come to the conclusion that calculating a standard MCI for each population provides an accurate method for sex assessment with accuracies that range from about 72% to as high as 87.5% (Rao et al., 1989; Reddy et al., 2008; Yadov et al., 2002). However, there are a number of articles that disagree with the accuracies and the usefulness of the MCI method and indicate that it should not be used for sex assessment, or at best used with caution and never by itself (Acharya & Mainali, 2009; Sharma & Gonea, 2010; Hosmani et al., 2013; Jacob et al., 2018; Krishran et al., 2016; Sekhone et al., 2017; Shahid et al., 2018; Silva et al., 2016). These studies all found that the MCI was not significantly different between males and females. Accuracy percentages for these studies have been as low as 24% for females when using a standard MCI calculated for the specific population (Acharya et al., 2011; Dony et al. 2018; Hosmani et al., 2013).

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Table 1: Studies with a Calculated Standard Mandibular Index (MCI)

Authors	Population	Sample size	Age range	MCI significant Y/N	Standard MCI	% Accuracy of standard MCI
Rao et al. 1989	South India	382	15–21	Y	0.274	84.3–87.5
Muller et al. 2001	Nice, France	424	17–24	Y	0.269	62.15–63.81
Yadav et al. 2002*	India	360	15–21	Y	0.298*	81–83.3
Kaushal et al. 2004	North India	60	17–21	Y	0.273 (right); 0.280 (left)	As high as 75
Reddy et al. 2008	Uttar Pradesh India	200	17–25	Y	0.256	66–78
Acharya and Mainali 2009	Dharan, Nepal	123	19–28	N	0.26	44.44–57.14
Mughal et al. 2010	Punjab Pakistan	200	18–25	Y	0.2504	71.67–78.72
Srivasatava 2010*	Uttar Pradesh India	400	17–21	N	0.257*	Unknown
Ren et al. 2010	Indonesia (Malaysian Indian)	216	18–28	Y	0.248	overall 76.67
Acharya et al. 2011	India	205	19–32	N	0.244	49.51–50.74
Sassi et al. 2012	Uruguay	112	21–60	Y	0.267	Unknown
Parekh et al. 2012*	Gujarat India	368	18–24	Y	0.205*	Unknown
Hosmani et al. 2013*	Belgaum India	50	15–21	N	0.27513*	40–50
Kakkar et al. 2013	Punjabi India	250	17–25	N	0.1903	53.54–55.03
Muhamedagić and Sarajlic 2013	Sarajevo, Bosnia, and Herzegovina	180	Unknown	Y	0.244	65.6–68.5
Ahmed 2014*	Iraq*	200*	17–23*	Y	0.26*	Unknown
Chakwujekwu et al. 2014*	Nigeria*	400*	17–308	Y	0.205(right); 0.215(left)*	Unknown
Dayananda et al. 2014*	India*	200*	18–22*	Y	0.270(right);0.276(left)*	Unknown
Edibamode et al. 2014*	Nigeria	184	18–35	Y	0.21*	Unknown
Narang et al. 2014	North India	410	20–40	Y	0.249	67.6–68
Paramkusam et al. 2014	India	120	18–25	N	0.26	76.66–80
Iqbal et al. 2015	Urumqi China	216	18–25	Y	0.248	overall 77

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Bakkannavar et al. 2015	South India	500	15–25	Y	0.2816(right); 0.2837 (left)	73.2–75.6
Latif et al. 2016	Haryana India	150	17–40	Y	0.257	76–78
Silva et al. 2016	Porto Portugal	120	16–30	N	0.282	25.7– 94
Krishnan et al. 2016	East India (Chennai)	50	18–25	N	0.25	52.5–60
Rajarathnam et al. 2016	Karnataka India	200	18–25	Y	0.255–0.26(right);0.25(left)*^	Up to 73
Patel et al. 2017	Gandhinagar India	400	20–40	Y	0.254	77.5–80
Gandhi et al. 2017	India	62	15–25	N	0.247	74.19–83.8
Rani 2017	India	180	18–25	left Y right N	0.5	Unknown
Shahid et al. 2018	Pakistan	128	18–24	N	0.25775	43.7–51.30
Bhagyashree et al. 2018	Maharashtra India	100	18–30	Y	0.265	61–75
Azevedo et al. 2019	Portugal	120	16–30	Y	0.303	57.1–72.0
Otuarga et al. 2019	Nigeria	201	17–25	Y	0.204(right);0.205(left)	Unknown
Modak et al. 2019	India	200	18–30	Y	0.2661	81–83
Current study	Kansas and Florida U.S.	45	14–51	N	0.242(right);0.246(left)	37–45

* Information from Dony et al. 2018;
^ Both in vivo and in veto calculated

When the Rao et al. (1989) standard MCI was applied to a Belgaum, India population the accuracy was only 45% (Hosmani et al., 2013). Limitations have been found with the mandibular canine index technique, including the fact that teeth not being in normal occlusion, can affect the results (Muller et al., 2001). Others have pointed out that all teeth need to be present for this technique to work (Acharya & Mainali, 2009). It is not uncommon for teeth to be pulled, or congenitally absent (Hillson, 1996). Teeth can also be lost postmortem. One study found that roughly 32–54% of canines were found to be absent postmortem (Oliveira et al., 2000). In addition, skeletal remains might exhibit teeth that are loose in the alveoli, affecting the measurements (Acharya & Mainali, 2009).

The present research examines the application of the MCI to two United States decedent samples to determine if the MCI is an accurate method for sex assessment in the U.S. when traditional methods are not applicable due to damaged or missing elements. This research seeks to validate the MCI method of sex assessment as outlined by Rao et al. (1989). This method has not yet been validated on a U.S. population. A standard mandibular canine index will also be calculated for the United States population and this will then be used to sort a

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test population to test the accuracy of the method. This study will also examine how the individual measurements, the mesio-distal length and the canine arch width, work as a method of sex assessment.

Materials and Methods

The study sample included 21 individuals from the C.A. Pound Human Identification Laboratory (CAPHIL) archived collection at the University of Florida in Gainesville, Florida along with 24 individuals from the Wichita State University Biological Anthropology Lab (WSU-BAL) donated collection in Wichita, Kansas for a total of 45 individuals. The individuals were chosen based on having a known identity, including biological sex, and having full dentition that was completely erupted and in relatively normal occlusion. Unknown individuals were excluded from the sample along with individuals that exhibited dental diseases, missing teeth, or malocclusion.

The measured sample consists of 23 females and 22 males between the ages of 14 and 51 years. The sample represents two ancestral groups: Americans of European decent ("White") and Americans of African descent ("Black").

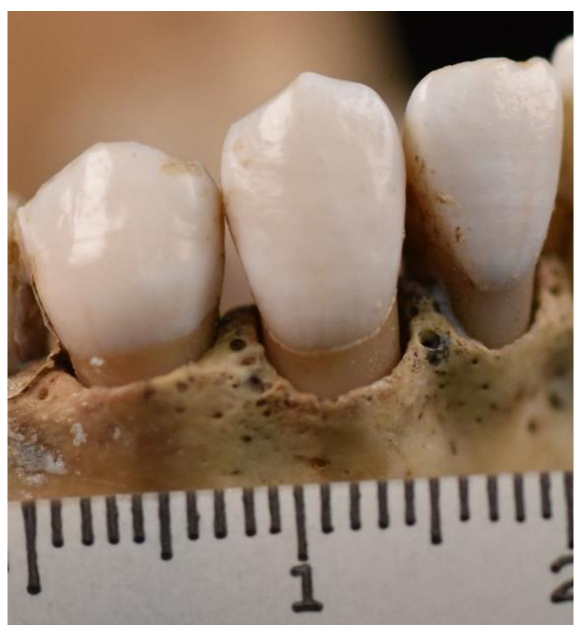
Measurements were taken in accordance with Rao et al. (1989). For all individuals in this study the mandible was disarticulated from the cranium, which would be similar to studies using dental casts. Calibrated digital calipers that measure down to a hundredth of a millimeter were used for all measurements. The maximum mesio-distal lengths of both mandibular canines were taken at the maximum distal point on each side of the tooth where it articulates with the adjacent tooth (**Figure 1**). The canine arch width was measured for each mandible by measuring between the apices of both mandibular canines (**Figure 2**; Rao et al.,1989). The mesio-distal length of the mandibular canine crown was measured and then divided by the width of the mandibular canine arch length to calculate the MCI. Each measurement was taken once.

Mesio-distal length/Canine arch width = MCI

For this study, the standard MCI was calculated using both the right and the left canine mesio-distal length for each individual. Once the MCI was calculated for each side, the standard MCI was calculated for each side using the following formula:

[(Mean male MCI-Standard Deviation (SD)) + (Mean female + SD)]/2 = Standard MCI

Figure 1: Right mandibular canine showing the mesio-distal length measurement.



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A value of less than or equal to the standard MCI would result in the individual being categorized as female, and a value greater than the standard would result in the individual being categorized as male. Twenty additional individuals were randomly selected from the WSU-BAL for testing of the standard MCI in order to determine the accuracy of the method.

An independent sample *t*-test was completed to determine if there are any significant differences between the male and female mesio-distal and canine arch width. A *t*-test was also done on the right and left MCI ratios to test for significance. The accuracy of the method was calculated by the standard MCI by calculating the frequency that the test individuals were placed in the correct group. For any measurements that resulted in a statistically significant difference between males and females, a sectioning point would be calculated by taking the male and female means and dividing by two. The sectioning point would then be tested for accuracy using the 20 as a additional individuals. Error rates for the population whole and the individual would be calculated for all measurements and the MCI using the methodology found in Klepinger (2006; pp. 39–41).

Results

The two ancestry groups were pooled due to the lack of significant differences between the groups (*p*-value of

Figure 2: Anterior view of mandible showing the canine arch width measurement.

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MCI = .64 for females and .34 for males). On average females had significantly smaller canine mesio-distal lengths than the male individuals (*p*=.002 for right and *p*=.001 for left). Female right canines averaged 6.63 mm (range 5.49–7.29 mm) compared to the male canines that averaged 7.11 mm (range 5.91–8.18 mm; **Table 2**). Female left canines averaged 6.7 mm (range 6.08–7.13 mm) while the male canines averaged 7.23 mm (range 5.88–8.16 mm; see **Table 2**). In general, left canines were slightly larger than right canines, although this was not significant (*p*=.39 for males and *p*=.25 for females). Males also had significantly larger canine arch widths (*p*=.02), with an average of 29.51 mm (range 23.71–37.22 mm) for the males, compared to an average of 27.48 mm (range 22.58–34.88 mm; see **Table 2**) for the females.

The sectioning points for the mesio-distal lengths and the canine arch width is listed in **Table 2**. With the right mesio-distal length 45% of the individuals sorted incorrectly, with 42% of males and 50% of females sorting incorrectly. The canine arch width had similar percentage of individuals who sorted incorrectly. The left side had the highest percentage of individuals who had their sex correctly assessed. For the left side 35% of the sample was sorted incorrectly, with 42% of males and 25% of females assigned the wrong sex. The error rates for the measurements were calculated. For a population that is assumed to be 50% males and 50% females, the right mesio-distal length has an error rate of 46% for females and 46% for males of being incorrectly sorted. The error rate for a single unknown individual is therefore, 46%. This means that 54% of the time the individual is assigned the correct sex. The canine arch width also has an error rate of 46% for males and 46% for females with a 46% error rate for a single individual in the population. For the left mesio-distal length, the error rate is 36% for females and 30% for males.

The chances of an unknown individual being assigned the incorrect sex is 33% (Klepinger 2006; pp. 39–41). When calculated the mandibular canine index showed no significant differences between males and females (**Table 3**) for either the right or left side. Using the right canine, the MCI ratio is 0.243 in females and 0.244 in males (*p*=.461). Using the left canine, the MCI ratio is 0.249 in females and 0.248 in males (*p*=.473; **Table 3**).

The calculated standard MCI for the right side was 0.242 (**Table 4**). The results show that 37% of males and 44% of females were sorted correctly using the standard MCI, for a 40% overall accuracy. The left side standard MCI was 0.246 (see **Table 4**). Forty-five percent of males and 44% of females were sorted correctly using the standard MCI for a 45% accuracy overall. In a population that is assumed to be 50% males and 50% females, the error rate for the right MCI is a 60% chance of incorrectly sorting as male and a 59% chance of being sorted as female. For a single individual, the error rate is 59.5% chance of being sorted incorrectly. For the left side MCI, the population error rate is a 55.4% chance of incorrectly sorting males and 55.6% chance of correctly sorting females. The individual error rate is 55.5% (Klepinger 2006; 39–41).

Discussion

This study agreed with the previous research in that there is a significant

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Table 2: Individual measurement

Measurement	Sex	Mean (mm)	Range (mm)	Standard Deviation (mm)	*P* value	Sectioning point
Right mesio-distal length	Females	6.63	5.49–7.29	0.393	.002	6.87
	Males	7.11	5.91–8.18	0.596		
Left mesio-distal length	Females	6.7	6.08–7.13	0.463	.001	6.97
	Males	7.23	5.88–8.16	0.551		
Canine arch width	Females	27.48	22.58–34.88	2.852	.019	28.5
	Males	29.51	23.71–37.22	2.971		

Table 3: Mandibular canine index (MCI)

	Sex	Mean (mm)	Range (mm)	Standard Deviation (mm)	*P* value
Right MCI	Females	0.243	0.197–0.310	0.027	.461
	Males	0.244	0.188–0.339	0.03	
Left MCI	Females	0.249	0.194–0.299	0.025	.473
	Males	0.248	0.197–0.339	0.031	

Table 4: Standard mandibular canine index

		Males		Female		Total	
	mm	Number	%	Number	%	Number	%
Right standard MCI	0.242	4/11	37%	4/9	44%	8/20	40%
Left standard MCI	0.246	5/11	45%	4/9	44%	9/20	45%

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difference between male and female mesio-distal length of their mandibular canines and that of the canine arch width. This appears to be a common consensus across the literature and with other studies on dental sexual dimorphism (e.g. Acharya & Mainali, 2009; Aggerwal et al., 2016; Parikh et al., 2013). However, when the sectioning points were tested by the testing population, the accuracy for the right mesio-distal length and the canine arch width were close to what chance would have been. The left mesio-distal length is slightly better with a 65% accuracy, but still not ideal. The greater accuracy of the left side is likely related to the greater sexual dimorphism of the left side (Aggerwal et al., 2016). When the error rates are taken into account, there is only a slightly higher than chance likelihood that the individual will be sorted into the correct sex using the right canine length and the width. The left side is slightly better, but still has a high error rate. The small sample size could be affecting the error rate. A study by Acharya and colleagues (2011) found slightly lower individual error rates for the right mesio-distal length and canine arch width (the left side was not calculated). Peckmann et al. (2016) found a similar error rate for the left mesio-distal length as this study.

This study failed to show that the MCI could increase the accuracy of the two measurements to the point where it could be a valid method of sex assessment in applied forensic anthropology. Unlike many of the studies conducted in India, there were no significant differences between male and female MCIs. There is only a very small difference (0.001) between the two sexes on both the right and the left side. The standard MCI (0.242 for the right and 0.246 for the left) accuracy predictions in this study are very low (40–45% overall), much lower than that of Rao et al. (1989) and lower than chance. However, the percentage is in line with other studies that did not find the MCI to be a useful sex assessment method (Acharya et al., 2011; Acharya & Mainali, 2009; Kakkar et al., 2013; Krishnan et al., 2016; Silva et al., 2016). There is a great deal of variation in the accuracy across the studies with males having a range of correct estimation of 32% to 94% and females having an accuracy range of 24-87%. According to the meta-analysis done by Dony et al. (2018) the exact reason for this is unknown. They looked at different variables such as population country (and then split the Indian studies into North and South India), age, and in vitro versus in vivo. They found that none of the smaller groups were themselves homogenous and none accounted for the variation (Dony et al., 2018).

In the current study there was too much overlap between the male and female MCI ranges for this method to be of utility for sex assessment. Some researchers have suggested that the tooth ratios, such as MCI, do not actually reflect the sexual dimorphism that absolute measurements such as the mesio-distal length have. Does the canine mesio-distal length actually have a relationship with the canine arch width that would lead to a ratio like the MCI being sexual dimorphic (Acharya & Mainali., 2009; Acharya & Mainali, 2007; Hosmani et al., 2013)? This can be seen in the present study where although the canine arch width is different in males than females, the largest canine size does not correspond to the largest canine arch width and the smallest canines do not correspond to the smallest canine width size.

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Most of the canine arch widths cluster around 25–26 mm and then 29–30 mm. The two measurements do not appear closely tied to each other at all for the most part.

Another issue is the fact that that a different standard MCI was calculated for each study with a range for most studies between 0.1903–0.5 (see **Table 1**). Each study population needed its own standard MCI. This means that there is no one standard MCI that will work over a large geographical area. India for example has a range of standard MCI from 0.1903–0.5. It is possible that a large diverse country like the United States would also have different standard MCIs based on regions and what populations are used. This also means that the standard MCI is not overly useful if the population the decedent is from is not known, which is not uncommon in a forensic context.

It should be noted that there is also an MCI using the same measurements except in the upper dentition (Bakkannavar et al., 2015; Nuhu et al., 2019; Otuagn et al., 2019; Phulari et al., 2017; Rani, 2017). In previous studies, it was found that the Maxillary Index results were not as significant as the Mandibular Index ones and thus not as accurate at assessing sex within the Indian populations (Nuhu et al., 2019; Otuagna et al., 2019). Other studies found that the Maxillary Canine Index was not significant at all and should not be used as a sexing method (Bakkannavar et al., 2015; Phulari et al., 2017). Due to these limitations, the Maxillary Canine Index was not assessed for this study.

From the above results, the Mandibular Canine Index is not an adequate tool for sex analysis in the U.S. based on the results from the CAPHIL and WSU-BAL populations, as well as the current literature. However, the sample size was small, and the study should be expanded to include a larger sample size to validate the results. The small sample size could have affected the results by decreasing the statistical power or introducing error. In addition, since the standard MCI needs to be adjusted for each population more studies should be done in the United States to see if there is the same wide range as in India. Another issue with the standard MCI is there has to be all of the mandibular canines and incisors present in normal occlusion in order for the method to be utilized. Many CAPHIL cases lack dentition or the dentition are not in normal occlusion thus they cannot be used for many of the forensic cases seen at the lab. The individual measurements that make up the ratio, the mesiodistal lengths and the canine arch widths, may be better sex assessment tools if the teeth are present. The left mesio-distal length in particular was the most significantly different between males and females in this study and can be used when the tooth is no longer in the alveoli, although due to the high error rate should not be used alone. More research needs to be done for both the MCI ratios and the individual tooth measurements with a larger sample size in order to determine in the results of this study is reflective of the greater U.S. population.

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