Sex determination using the mesio-distal dimension of permanent maxillary incisors and canines in a modern Chilean population

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Sex determination using the mesio-distal dimension of permanent maxillary incisors and canines in a modern Chilean population

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ABSTRACT

The pelvis and skull have been shown to be the most accurate skeletal elements for the determination of sex. Incomplete or fragmentary bones are frequently found at forensic sites however teeth are often recovered in forensic cases due to their postmortem longevity. The goal of the present research was to investigate sexual dimorphism between the mesio-distal dimension of the permanent maxillary incisors and canines for the determination of sex in a contemporary Chilean population. Three hundred and three dental models (126 males and 177 females) from individuals ranging in age from 13 years to 37 years old were used from the School of Dentistry, University of Chile. The statistical analyses showed that only the central incisors and canines were sexually dimorphic. Discriminant function score equations were generated for use in sex determination. The average accuracy of sex classification ranged from 59.7% to 65.0% for the univariate analysis and 60.1% to 66.7% for the multivariate analysis. Comparisons to other populations were made. Overall, the accuracies ranged from 54.4% to 63.3% with males most often identified correctly and females most often misidentified. The determination of sex from the mesio-distal width of incisors and canines in Chilean populations does not adhere to the Mohan and Daubert criteria and therefore would not be presented as evidence in court.

1. Introduction

Between 1973 and 1990 General Augusto Pinochet led a dictatorship in Chile. The Pinochet regime implemented the systematic practice of forced disappearances and extrajudicial killings [1]. A total of 3227 individuals have been declared missing with 1465 of these individuals identified as cases of detenidos-desaparecidos, or enforced disappearances [2]. The transition to democracy in Chile needs to include locating and identifying these individuals [3].

When identifying human remains, the determination of sex is of primary significance as the determination of stature and age at death is sex dependent. The pelvis and skull have been shown to be the most accurate skeletal elements for the determination of sex [4–7]. However, incomplete or fragmentary bones are frequently found at forensic sites due to postmortem damage and taphonomic changes.

Teeth are often recovered in forensic cases due to their postmortem longevity as they are highly resistant to physical and chemical influences. Teeth are the hardest and most durable material in the human body. They are more resilient than bone and are often the only human material recovered in mass disasters. Dentition offers vast amounts of information for the forensic anthropologist and odontologist. They can provide an estimation of sex, age, diet, and geographic origin for the unknown individual [8–10]. Research has shown that tooth crown diameters are clinical markers for sex differentiation [11–31].

The mesio-distal dimension of permanent teeth has been studied, for determination of sex, in populations from Southern China [11], Saudi Arabia [12,13], Japan [14], Turkey [15], Nigeria and Britain [16], India [17–23], the Philippines [24,25], Sweden [26], Brazil [27], Nepal [28,29], Greece [30], and White Americans [31]. The permanent maxillary and mandibular incisors and canines are advantageous for sex estimation as they are the least frequently extracted teeth and are less often affected by periodontal disease [32–34]. Research has shown that estimation of sex from the mesio-distal dimension of maxillary incisors and canines is population specific [11–31]. The accuracy rates for mesio-distal dimensions of maxillary incisors and canines for sex estimation in a contemporary Chilean population have not been investigated to date. This research will therefore assist in the identification of unknown individuals of Chilean ancestry.

The goals of this research are to (1) investigate sexual dimorphism between the mesio-distal dimension of the permanent maxillary

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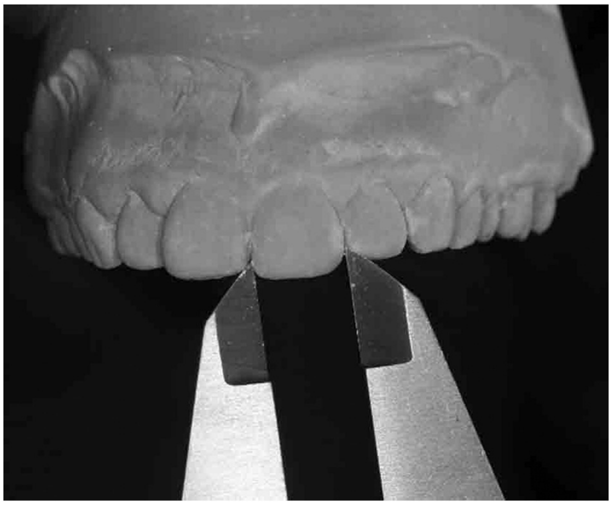

Fig. 1. Mesio-distal measurement of the central incisor.

incisors and canines, and (2) test the accuracy of the mesio-distal dimension of the permanent maxillary incisors and canines for the determination of sex in a contemporary Chilean population.

2. Materials and methods

This research utilized 303 dental models (126 males and 177 females) from the Instituto Nacional de Ortodoncia, Chile. The individuals ranged in age from 13 years to 37 years old and had birth dates from 1970 to 2000 and therefore this sample represents a contemporary Chilean population. On becoming a patient at this clinic, each person is required to sign a consent form for use of their models for research. Age and sex demographics about each individual are known.

The greatest mesio-distal dimension of the permanent left and right maxillary incisors and canines was measured. The mesio-distal dimension is defined as the maximum distance between the most mesial and the most distal point of the crown (Figs. 1 and 2).

The teeth utilized included:

Tooth 1.1 — Right central incisor
Tooth 1.2 — Right lateral incisor
Tooth 1.3 — Right canine
Tooth 2.1 — Left central incisor
Tooth 2.2 — Left lateral incisor
Tooth 2.3 — Left canine

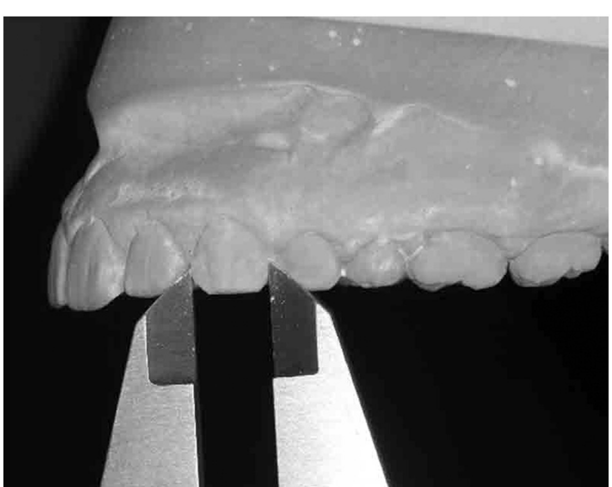

Fig. 2. Mesio-distal measurement of the canine.

Table 1
Descriptive statistics for the Chilean population.

Tooth	Males			Females			Overall
	n	Mean (mm)	Standard deviation (mm)	n	Mean (mm)	Standard deviation (mm)	% Sexual dimorphism[a]
1.3	126	8.367	0.482	177	7.977	0.482	4.89
1.2	126	7.014	0.531	177	6.960	0.615	0.76
1.1	126	8.819	0.529	177	8.606	0.510	2.48
2.1	126	8.953	0.465	177	8.696	0.492	2.96
2.2	126	7.149	0.498	177	7.020	0.589	1.84
2.3	126	8.363	0.431	177	7.969	0.565	4.94

[a] % Sexual Dimorphism: [(male mean − female mean)/female mean] × 100.

All metric values were collected by one observer with a digital vernier caliper and measured to the nearest 0.0 l mm. Criteria for inclusion included fully erupted permanent maxillary incisors and canines that were peridontally healthy with normal occlusion and no spacing, crowding, attrition, caries, dental fillings, history or clinical evidence of crown restoration, orthodontic treatment, or trauma. This protocol follows that of other researchers [11,13–16,19,25,26]. Intra- and inter-observer error rates were calculated by re-measuring 20 randomly selected individuals (10 males and 10 females). The measurements between observers were collected one week a part.

Statistical analyses were performed with the SPSS (version 21.0) software program using a Bonferroni-adjusted level of significance. Normality and independent *t*-tests were conducted using Minitab (version 17). Descriptive statistics were obtained for each measurement (Table 1). Males and females were analyzed separately. Using a two sample *t*-test the mean values of the measurements were compared between the sexes to determine if statistically significant differences existed. The variables were subjected to direct and stepwise discriminant function analyses. The Chilean teeth measurements were compared with other populations, separately two by two, using two sample *t*-tests: Northern India [18,21], Brazil [27], Nepal [29], Iraq [28], Saudia Arabia [12], and Southern India [17]. Although raw data was unavailable for the comparative populations, Minitab allows the use of summarized data (e.g. sample size, mean, standard deviation) from two samples to conduct a two-sample *t*-test. A paired *t*-test was used to calculate the intra- and inter-observer error rates for each measurement variable. Each variable of the incisors and canines was re-measured from each of the 20 individuals, i.e. all variables were measured three times: original data, intra-observer data, inter-observer data. Paired *t*-tests were then carried out on each variable comparing the difference between the original and re-measured values.

All data were tested for normality and all variables were normally distributed using a Bonferroni-adjusted level of significance $p < 0.004$; males and females were tested separately and all ages combined. As

Table 2
Intra- and inter-observer error rates for the Chilean population.

Tooth	*n*	Mean difference (mm)	*t*-value	p-value
Intra-observer error				
1.3	20	−0.007	−0.180	0.859
1.2	20	0.080	−1.170	0.273
1.1	20	−0.087	−2.130	0.062
2.1	20	−0.093	−2.080	0.067
2.2	20	0.290	1.080	0.307
2.3	20	0.090	1.350	0.211
Inter-observer error				
1.3	20	0.194	2.45	0.037
1.2	20	0.231	3.31	0.009
1.1	20	0.140	1.45	0.182
2.1	20	0.104	1.22	0.254
2.2	20	0.326	1.20	0.260
2.3	20	0.272	3.16	0.012

*$p < 0.008$; Bonferroni correction.

Table 3
Sexual dimorphism between males and females of the Chilean population.

Tooth	Mean difference (mm)	DF	*t*-value	p-value	95% CI of the difference	
					Lower	Upper
1.3	0.389	269	6.93	0.000*	0.279	0.500
1.2	0.054	289	0.82	0.412	−0.076	0.184
1.1	0.213	263	3.51	0.001*	0.093	0.333
2.1	0.257	277	4.62	0.000*	0.147	0.366
2.2	0.129	292	2.06	0.040	0.005	0.252
2.3	0.394	299	6.88	0.000*	0.281	0.507

*$p < 0.008$; Bonferroni correction.

the variables were not skewed, means and standard deviations were used as the most appropriate measures of central tendency. The two-sample and paired *t*-tests were selected as the appropriate statistical tests because the samples were randomly selected, the variances were similar for the measurements, and the data exhibited a normal distribution.

3. Results

3.1. Inter- and intra-observer error rates

Using the Bonferroni-adjusted level of significance ($p < 0.008$) none of the tests were statistically significant for any of the variables therefore there were no differences between or within observers (Table 2). Statistically acceptable coefficients of reproducibility could be obtained.

3.2. Assessment of sexual dimorphism

Table 3 shows the results for the assessment of sexual dimorphism. The p-values are less than the Bonferroni-adjusted level of significance ($p < 0.008$) for teeth 1.3, 1.1, 2.1, and 2.3 indicating the presence of significant sexual dimorphism in the measured variables. However, the p-values are greater than 0.008 for teeth 1.2 and 2.2 indicating no sexual dimorphism in these teeth. Therefore, teeth 1.2 and 2.2 were omitted from the discriminant function testing.

3.3. Discriminant function equations

Table 4 shows the unstandardized discriminant function coefficients, constants, and accuracy rates for combinations of teeth that were entered directly into, and used for, the discriminant function analyses. For the direct discriminant function equations, the overall tested accuracy of sex determination ranged from 60.1% to 66.7%. The accuracy of sex determination ranged from 61.1% to 65.9% for males and 59.3% to 67.2% for females. Overall, function 1 (66.7%) that included all four teeth was the best combination. Function 3 (66.0%) that included teeth 1.3 and 2.3 showed higher accuracy rates than function 2 (60.1%), which included teeth 1.1 and 2.1.

For the univariate discriminant function equations, the overall tested accuracy of sex determination ranged from 59.7% to 65.0% (Table 4). The accuracy of sex determination ranged from 54.0% to 66.7% for males and 58.8% to 66.1% for females. Function 6 (65.0%), which included tooth 1.3 was the most accurate overall and function 5 (59.7%) that included tooth 2.1 showed the lowest accuracy rate.

The unstandardized coefficients, constants, and sectioning points that were used to formulate the discriminant function equation are displayed in Table 5. A y-value greater than or equal to the sectioning

Table 4
Discriminant function analysis for the Chilean population.

Function	Variable (tooth)	Standardized coefficient	Unstandardized coefficient	Constant	Wilks' lambda	Centroids		Classification accuracy					
						Male	Female	Male		Female		Overall	
								%	*n*	%	*n*	%	*n*
Multivariate discriminant function													
	1.3	0.552	1.144										
1 – Central incisors and canines	1.1	−0.065	−0.125	−19.796	0.840*	0.516	−0.368	65.9	83/126	67.2	119/177	66.7	202/303
	2.1	0.271	0.563										
	2.3	0.418	0.813										
2 – Paired central incisors	1.1	0.129	0.249	−18.719	0.934*	0.313	−0.223	61.1	77/126	59.3	105/177	60.1	182/303
	2.1	0.905	1.880										
3 – Paired canines	1.3	0.617	1.279	−17.963	0.846*	0.505	−0.359	65.9	83/126	66.1	117/177	66.0	200/303
	2.3	0.477	0.928										
Univariate discriminant functions													
4 – Right central incisor	1.1	1	1.931	−16.787	0.960*	0.240	−0.171	54.0	68/126	64.4	114/177	60.1	182/303
5 – Left central incisor	2.1	1	2.078	−18.296	0.935*	0.312	−0.222	61.1	77/126	58.8	104/177	59.7	181/303
6 – Right canine	1.3	1	2.072	−16.868	0.863*	0.472	−0.336	63.5	80/126	66.1	117/177	65.0	197/303
7 – Left canine	2.3	1	1.946	−15.829	0.874*	0.448	−0.319	66.7	84/126	62.1	110/177	64.0	194/303

n = *n* correctly classified individuals/*n* total individuals.
* $p < 0.001$.

Table 5
Discriminant function equations and sectioning points for the Chilean population.

Function	Equation	Sectioning point[a]
1 – Central incisors and canines	$y = -19.796 + (-0.125)(\text{Tooth } 1.1) + (1.444)(\text{Tooth } 1.3) + (0.563)(\text{Tooth } 2.1) + (0.813)(\text{Tooth } 2.3)$	0.074
2 – Paired central incisors	$y = -18.719 + (0.249)(\text{Tooth } 1.1) + (1.880)(\text{Tooth } 2.1)$	0.045
3 – Paired canines	$y = -17.963 + (1.279)(\text{Tooth } 1.3) + (0.928)(\text{Tooth } 2.3)$	0.073
4 – Right central incisor	$y = -16.787 + (1.931)(\text{Tooth } 1.1)$	0.034
5 – Left central incisor	$y = -18.296 + (2.078)(\text{Tooth } 2.1)$	0.045
6 – Right canine	$y = -16.868 + (2.072)(\text{Tooth } 1.3)$	0.068
7 – Left canine	$y = -15.829 + (1.946)(\text{Tooth } 2.3)$	0.065

[a] If y-value ≥ sectioning point, the individual is classified as male.

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Table 6
Leave-one-out cross-validation classification accuracies for the Chilean population.

Function	Classification accuracy					
	Males		Females		Overall	
	%	*n*	%	*n*	%	*n*
Multivariate discriminant functions						
1 — Paired central incisors and canines	65.1	82/126	65.5	116/177	65.3	198/303
2 — Paired central incisors	60.3	76/126	58.8	104/177	59.4	180/303
3 — Paired canines	65.9	83/126	66.1	117/177	66.0	200/303
Univariate discriminant functions						
4 — Right central incisor	54.0	68/126	64.4	114/177	60.1	182/303
5 — Left central incisor	61.1	77/126	58.8	104/177	59.7	181/303
6 — Right canine	63.5	80/126	66.1	117/177	65.0	197/303
7 — Left canine	66.7	84/426	62.1	110/177	64.0	194/303

point classifies the individual as male and a y-value less than the sectioning point classifies the individual as female.

Table 6 shows the leave-one-out cross-validation accuracy rates for the Chilean population. Overall, there is less than one percent difference between the discriminant function classification accuracies and the cross-validation classification accuracies. This indicates that the discriminant functions created for the Chilean population accurately classify the data.

3.4. Comparison to other populations

The population specificity of the two Northern Indian [18,21] discriminant function equations was tested. The Chilean metric data were entered into the discriminant function equations created from the two Northern Indian populations [18,21] (Table 7). These were the only published discriminant functions available for comparison that used the same variables. When applied to a modern Chilean population, the discriminant function from the Northern Indian I [18] (54.4%) and Northern Indian II [21] (63.3%) populations showed about the same overall accuracy rate as their population-specific equations (61.0% for Northern India I, 60.3% for Northern India II) for sex determination. Males were more accurately classified (98.4% for Northern India I, 76.9% for Northern India II) than females (23.1% for Northern India I, 53.6% for Northern India II).

Table 8 shows the comparison of Chilean maxillary mesio-distal teeth measurements with other populations: Northern India [18,21], Brazil [27], Nepal [29], Iraq [28], Saudi Arabia [12], and Southern India [17]. This analysis used a Bonferroni-adjusted level of significance $p < 0.0125$ for four comparisons (four teeth) and $p < 0.025$ for two comparisons (two teeth). For teeth 1.3 and 2.3, both males and females of the Northern Indian II [21], Saudi Arabian [12], and Southern Indian [17] populations showed significant differences when compared to the Chilean population. For tooth 2.1, only males and females of the Nepalese [29] population showed significant differences when compared to the Chilean population. Tooth 1.1 showed no significant differences when compared to the Chilean sample.

4. Discussion

For scientific methodologies, it is essential that measurement parameters are well defined and researchers using those parameters are able to reproduce the measurement. The results of the intra- and inter-observer error analyses show that none of the comparisons were statistically significant therefore there were no differences within or between observers. Statistically acceptable coefficients of reproducibility could be obtained.

In the Chilean population, the mesio-distal dimension of teeth 1.3, 1.1, 2.1, and 2.3 showed statistically significant sex differences between males and females, indicating that they are sexually dimorphic. However, teeth 1.2 and 2.2 displayed no sexual dimorphism. Similar conclusions were cited by other researchers [21,29]. Except for tooth 2.1 in the Nepalese [29] sample, the mean mesio-distal width was larger in males than in females for all of the populations. This is similar to conclusions by Sherfudhin et al. [20] and Parekh et al. [35]. However, Kalia [36] found no sexual dimorphism between males and females in his study. The results of the current study are also consistent with previous research that found canines to be the most dimorphic teeth [15,22,23,26,30,37–43] (Table 3). Frayer and Wolpoff [44, p.453] cite that "the canine dimorphism cannot be matched in any living or fossil anthropoid species". Sexual dimorphism may also be due to biological variation, which is influenced by genetics and environmental factors [19,45].

Several studies have examined the morphological and developmental differences in the dentition of males and females. Schwartz and Dean [46] suggested that sex hormone concentrations during dental development may be related to the differences between males and females. Vieira [47] suggested that genetic factors may be involved with particular types of tooth development. Smith et al. [48] studied the molar teeth and found that males exhibited significantly greater dentine area, enamel–dentine junction shape, and bi-cervical diameters in certain tooth types while females had significantly thicker average enamel. Saunders et al. [49], also cite that male canines and premolars have significantly more dentine than females and relatively more dentine with respect to overall crown size. They also show that the female canines and premolars have significantly more enamel relative to overall crown area than the males. All of these factors may be related to crown size differences found between males and females.

Overall, the accuracies obtained from the use of multiple variables for the Chilean sample ranged from 60.1% to 66.7%, which is similar to those observed for the Northern Indian I [18] (58% to 64%) and Northern Indian II [21] (58.7% to 62%) populations. For the multivariate discriminant analysis, function 1 which utilized teeth 1.3, 1.1, 2.1, 2.3 showed the highest overall accuracy rate (66.7%). Although, the univariate analysis illustrates that function 6 which only used tooth 1.3 also shows very similar accurate rates (65.0%) as function 1. In forensic situations, not all teeth may be present therefore the univariate analyses may prove useful in these circumstances. The Northern Indian I [18],

Table 7
Accuracy of the two Northern Indian discriminant function equations when applied to the Chilean population.

Population	Author	Variables	Original discriminant function classification accuracy (%)	Classification accuracy of the Chilean data set						Overall classification difference between populations (%)
				Male		Female		Overall		
				%	*n*	%	*n*	%	*n*	
N. India I	Khangura et al. [18]	1.3 2.3	61.0	98.4	124/126	23.1	41/177	54.4	165/303	6.6
N. India II	Srivastava et al. [21]	1.1 1.3 2.1 2.3	60.3	76.9	97/126	53.6	95/177	63.3	192/303	3.0

$n = n$ correctly classified individuals/n total individuals

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Table 8
Comparing the tooth dimensions of the Chilean population to other populations.

	Authors	Present study			Khangura et al. [18]			Srivastava et al. [21]			Sabóia et al. [27]			Acharya and Mainali [29]			Nahidh et al. [28]			Al-Rifaiy et al. [12]			Boaz and Gupta [17]		
	Population	Chile			N. India I			N. India II			Brazil			Nepal			Iraq			Saudi Arabian			S. India		
Sex	Variables	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	*SD*	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD	*n*	Mean (mm)	SD
Male	1.3	126	8.37	0.48	50	7.63	0.60	150	9.85*	0.51	50	8.32	0.50	64	7.94	0.45	100	7.99	0.43	251	6.94†	0.66	50	7.81†	0.55
Female	1.3	177	7.98	0.48	50	7.38	0.64	150	8.65*	0.56	50	7.94	0.50	58	7.60	0.40	100	7.53	0.44	252	6.80†	0.93	50	7.69†	0.58
Male	2.3	126	8.36	0.43	50	7.72	0.57	150	9.83*	0.48	50	8.32	0.48	64	7.89	0.45	100	7.94	0.49	251	6.91†	0.65	50	7.80†	0.58
Female	2.3	177	7.97	0.56	50	7.45	0.63	150	8.68*	0.51	50	7.96	0.52	58	7.56	0.37	100	7.49	0.40	252	6.83†	0.93	50	7.68†	0.56
Male	1.1	126	8.82	0.53	–	–	–	150	8.99	0.58	50	8.91	0.55	63	8.79	0.62	–	–	–	–	–	–	–	–	–
Female	1.1	177	8.61	0.51	–	–	–	150	8.70	0.54	50	8.68	0.57	57	8.52	0.55	–	–	–	–	–	–	–	–	–
Male	2.1	126	8.93	0.46	–	–	–	150	8.98	0.59	50	8.90	0.53	65	7.42*	0.55	–	–	–	–	–	–	–	–	–
Female	2.1	177	8.70	0.49	–	–	–	150	8.68	0.56	50	8.65	0.55	58	8.48*	0.52	–	–	–	–	–	–	–	–	–

†$p < 0.025$; Bonferroni correction.
*$p < 0.0125$; Bonferroni correction.

Northern Indian II [21], and Chilean population studies demonstrated higher accuracies when multiple combinations of variables were utilized suggesting that individual variables should only be used when single teeth are recovered.

Overall accuracy rates for the Chilean group (59.7% to 66.7%) are similar to that found in the Northern Indian I [18] (61%), Northern Indian II [21] (60.3%) and Saudi Arabian [12] (65.48%) populations but lower than that cited for the Nepalese [29] (67.9% to 92.5%) and Iraqi [28] (73.0%) groups. Sherfudhin et al. [20] also studied an Indian population and found very high (87.38%) accuracy rates.

In Canada and the United States, judicial laws cite that scientific methodologies used by expert witnesses must meet the Mohan [50] and Daubert [51] criteria for admissibility [52,53]. Greater than or equal to 80% accuracy rate with an intra-observer error rate less than or equal to 10% has been cited as the minimum standard needed for a methodology to meet the Mohan [50] and Daubert [51] criteria [54]. Due to the potential error rates cited in this research, determination of sex from the mesio-distal width of incisors and canines in Chilean populations does not adhere to the Mohan [50] and Daubert [51] criteria and therefore would not be presented as evidence in court; this is a presumptive test that could be used in addition to other more accurate methodologies in forensic situations.

Table 7 shows the Chilean metric data entered into the discriminant function equations from other population groups: Northern Indian I [18] and Northern India II [21]. When applied to a Chilean population, the discriminant functions from the other two populations yielded approximately the same accuracy rates (54.4% to 63.3%) for sex determination as the Chilean-specific equations (59.7% to 66.7%). This suggests that there may not be a need for population specific discriminant function equations for the determination of sex from the mesio-distal dimensions of canines and incisors for these specific populations.

Table 8 shows a comparison of the Chilean mean values with other population groups. Overall, the Chilean teeth measurements were larger than the Northern Indians I [18], Nepalese [29], Iraqi [28], Saudi Arabians [12], and Southern Indians [17]. However, overall, the Chilean teeth measurements were smaller than the Northern Indians II [21] and about the same size as the Brazilians [27]. The majority of comparisons did not show statistically significant differences between population groups, suggesting that discriminant functions developed from one population group can be used to discriminate sex when used on another population. Although in all cases the accuracy rates are only approximately 60% to 65%.

Due to their composition, teeth do not remodel or grow once they are formed. Research suggests that using discriminant functions from the dentition may be the most reliable method for the determination of sex in subadults [55]. However, the results of this study demonstrate low accuracy rates for the determination of sex from the mesio-distal diameter of incisor and canine teeth in Chilean populations. This study also shows that discriminant functions developed from one population group can be used to discriminate sex when used on another population. Multivariate discriminant functions provided the highest level of accuracy (66.7%), however, one univariate analysis using tooth 1.3 showed very similar accurate rates (65.0%). Due to the potential error rates cited in this research, determination of sex from the mesio-distal diameter of incisor and canine teeth in Chilean populations does not adhere to the Mohan [50] and Daubert [51] criteria and therefore would not be presented as evidence in court; this is a presumptive test that could be used with other more accurate methodologies in forensic situations. Future research should investigate the relationship between tooth wear and the mesio-distal diameter of incisor and canine teeth.

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