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The Effect of Shovel Trait on Carabelli's Trait in Taiwan Chinese and Aboriginal Populations*

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ABSTRACT: Chinese and other Mongoloid populations differ from Caucasoids by having a high prevalence of shovel trait and a low prevalence of Carabelli's trait. This study was conducted to compare the association between the shovel and the Carabelli's traits between Chinese and aboriginal Mongoloid populations. The research is designed to sample randomly a Chinese population and an aboriginal population having low admixture with neighboring populations. The Mongoloid aboriginal group was from the Bunun tribe who resides in an isolated alpine area in Taiwan. The effects of sex and age on Carabelli's trait were controlled in this study, as was the association between tooth size and Carabelli's trait. Our results show that males had more Carabelli's trait expressed on teeth than females in both of these two Mongoloid populations. The buccolingual diameter of Carabelli's trait teeth was larger than that of teeth without the trait. After controlling for sex, age, and tooth size, the existence of the shovel trait significantly increased the likelihood of having Carabelli's trait, especially in Chinese, which implies another significant ethnic feature for Mongoloid identification.

KEYWORDS: forensic science, forensic odontology, forensic anthropology, ethnic dental traits, Mongoloid, Chinese, aboriginal, physical anthropology, multivariate logistic regression, Taiwan

Shovel trait incisors and Carabelli's trait molars are commonly used by forensic scientists to help identify ethnic categories (1–3). Shovel or Carabelli's traits have been used as important indicators for several decades, probably because teeth are simply observed in both living and skeletal materials and they can be used to show major ethnic differences in dentition (4). Mongoloid dental complex has two major features: a high frequency of shovel incisors and a low frequency of Carabelli's trait molars (5–6). Although the preliminary positive association between shovel and Carabelli's traits in a Mongoloid population has been reported, the real association between these two dental traits is still unclear (7). In order to add to this clarifications, the present study will compare the association between these two traits in Chinese and Bunun aboriginal populations.

Regarding the morphology of the traits, shovel traits are a combination of a concave lingual surface and elevated marginal ridges enclosing a central fossa in the upper central incisor teeth (Fig. 1). Carabelli's traits are found on the lingual aspect of the mesiolingual cusp of the upper first molar teeth on which the traits may take the form of a pit, fissure, or cusp. Very few studies have investigated the degree to which the existence of the shovel trait in the incisor teeth affects the Carabelli's trait in the molar teeth, although different dental inter-trait studies have been done before (7–8).

To reduce the possible population admixture, we investigated a Chinese and an aboriginal populations, respectively. The Chinese people who live in Taiwan are the descendants of Chinese mainlanders that migrated to Taiwan largely from Fukien and Kwantung in the period after 1600s (9). Before the migration, the aborigines had already been already living in Taiwan. The Bunun aborigines reside in isolated alpine area of central and southern Taiwan and have little admixture with non-Bunun peoples. Anthropologically Taiwan aborigines migrated from the south Asian mainland several thousand years ago and belong to the proto-Malays (10–13). Besides reducing the impact of population differences, we had to

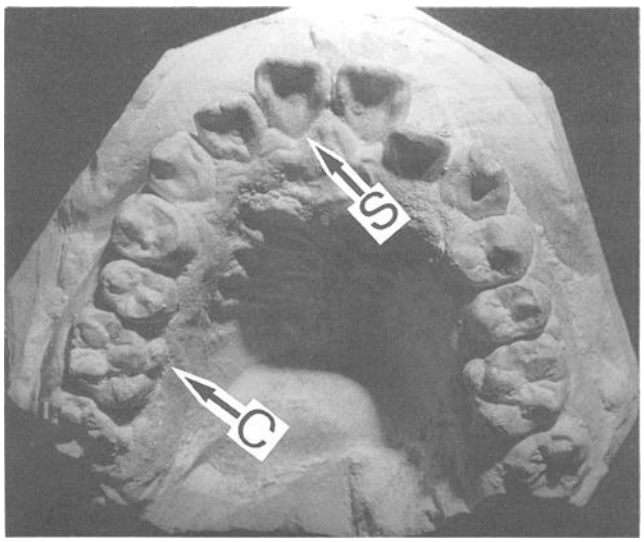

FIG. 1—*Cusp form of Carabelli's trait (C) on upper right first molars and shovel trait (S) on upper central incisors.*

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consider another possible factor, sex, which might affect the value for Carabelli's trait and might interfere with the association between the shovel trait and Carabelli's trait in these two populations. Although some authors have found differences between the sexes in the expression of Carabelli's trait have been reported (14–15), other authors have found no significant male-female differences in Carabelli's trait (16–17). To control potential effects caused by dimorphism, sex was viewed as a possible confounding variable in our study.

The correlation between the increased maxillary molar tooth size and the occurrence of Carabelli's trait has been previously reported (18) and tooth size of Carabelli trait-positive molars is larger than that of Carabelli trait-negative molars (19). Therefore, since tooth size may also be a confounding factor in our analysis of Carabelli's trait, we controlled the tooth size. Our study investigates the differences in such confounding variables as demography and tooth size, according to Carabelli's trait in a Chinese and an aboriginal populations. After removing the effects of possible confounding variables, the present study may also seek to investigate the extent to which the shovel trait might affect Carabelli's trait in these two populations.

Methods and Materials

Measurement Acquisition

In this study, 329 Chinese and 244 aboriginal subjects were considered. In order to reduce the confounding effects of the admixture of race on Carabelli's trait, subjects had to be members of the Chinese population or the Bunun tribe of Taiwan aborigines. To lower the possible discrepancy between deciduous and permanent dentitions, this study was confined to permanent teeth. To avoid the decrease in observable characteristics caused by dental caries and wear related to advancing age, the subjects were restricted to adolescents between the ages of 12 and 15 years old, and the age effect was further controlled and included in the statistical model. Tooth impressions were taken and plaster models were made with rigid disposable trays, into which dental stone was poured immediately to prevent distortion.

For morphological and metric inspections, 573 dental casts were used. For upper right first molar and upper right central incisor measurements, 309 of 329 Chinese dental casts and 229 of 244 aboriginal casts could be appraised. Thirty-five casts were excluded due to an inability to measure tooth size and traits. There was no significant variation in demography between the studied group of casts and the excluded group of casts for each population. To eliminate potential problems of asymmetry, analysis was limited to traits and measurements of the right side of the dentition (20). Even if a tooth was missing or could not be accurately measured due to the loss of measuring points through caries, restoration or attrition, the corresponding contralateral tooth was not used as a proxy.

Carabelli's trait has been classified into various patterns: (a) no evidence of Carabelli's trait—smooth surface with the absence of pits or fissures, (b) pits or fissures, (c) cusp without free tip and cusp with free tip in the report of Kraus in 1951 (21). Subsequently, more patterns of Carabelli's trait have been described, and even intermediate forms have been introduced (17,22). The nonmetrically categorical data of trait patterns have been dichotomized into two groups, including the existence and the nonexistence of Carabelli's traits. When any manifestation of the trait, cusp, fissure, or pit on the upper right first molar was noticed, the presence of Carabelli's trait was recorded.

Various patterns of the shovel trait have been suggested and contain (a) shovel—enamel rim distinct with an enclosed well-developed fossa, (b) semishovel—enamel rim distinct but enclosed fossa shallow, (c) trace shovel—traces of enamel rim which can not be classed as semi-shovel, and (d) no shovel—no perceptible trace of rim or fossa (23). Upper right central incisor teeth were inspected by using this system of grouping and the modified classifications (22,24). These categorical figures were also dichotomized into two types, including the existence and the nonexistence of shovel traits. The shovel trait-positive incisors were coded when rim or fossa could be found.

Regarding the measure device, tooth size of the upper right central incisors or the upper right first molars of permanent teeth for each dental cast was measured by a sliding electronic digital caliper with 0.01-mm resolution. Tooth size variables included mesiodistal and buccolingual diameters for incisors or molars. The measurements of mesiodistal and buccolingual diameters followed the procedures used by Seipel (25) and Moorrees et al. (26). Mesiodistal diameter was defined as the greatest distance between the approximate surfaces of the crown with a sliding caliper parallel to the occlusal and vestibular surfaces of the crown. When a tooth was rotated or malposed in relation to the dental arch, the measurement was taken between the points on the approximate surface of the crown at which place it was judged that normal contact should have occurred with neighboring teeth. Buccolingual diameter was defined as the greatest distance between the labial or buccal surface and the lingual surface of the tooth crown, measured with a sliding caliper held at right angles to the mesiodistal diameter. Carabelli's cusp is not included in the measurement of buccolingual diameter.

The mesiodistal and buccolingual crown dimensions of the upper right central incisors or the upper right first molars were measured directly on the cast by a single well-trained examiner to limit interobserver errors. A significant test-retest reliability ($r > 0.95$, $p < 0.001$) was noticed. Diameters were measured three times and the average value was recorded for each diameter. The morphological traits were classified independently by another examiner, whose incorrect percentage of trait classification was less than 4% in this study.

Statistical Analysis

The confounding variables were calculated for means and proportions according to the teeth with vs. without Carabelli's trait in each population. Multivariate logistic regression was applied in this comparative dichotomy analysis between the two groups with the use of the SAS/STAT computer program (27). We used logistic regression which has become a common method of analysis in studies in which the dependent outcome variable, in our case, the presence or absence of Carabelli's trait, is dichotomous or discrete. Due to the possible variation of dental size and morphology, age was controlled for in this investigation. Besides sex, the diameters of teeth were also controlled for in the analysis to explore the differences in Carabelli's traits of upper right first molars between presence and absence of shovel traits of upper right central incisors. This logistic method enabled the comparison between presence and absence of the shovel trait for the differences in Carabelli's trait, while controlling for the effects of independent variables such as sex, age, and size of the upper right central incisors and the upper right first molars concurrently. Tests for inference allowed a type I error rate of 5%. The odds risk and 95% confidence interval of odds risk were computed. Odds risk is a measure by which

TABLE 1—*Characteristics of Bunun aborigine and Chinese according to Carabelli's trait (C.T.).*

Characteristics	Bunun				Chinese			
	C.T. N = 109 (47.60%)	vs. vs.	No C.T. 120 (54.40%)	Total N = 229 (100.00%)	C.T. N = 114 (36.89%)	vs. vs.	No C.T. 195 (63.11%)	Total N = 309 (100.00%)
Sex (% Male)	74.31		40.83	56.77	76.32		44.61	56.31
Age (Mean ± SD Years)	13.37 ± 0.71		13.49 ± 0.68	13.43 ± 0.70	13.48 ± 0.69		13.54 ± 0.72	13.51 ± 0.71
MD URI1 (Mean ± SD mm)*	8.40 ± 0.55		8.22 ± 0.52	8.31 ± 0.53	8.63 ± 0.58		8.45 ± 0.54	8.52 ± 0.56
BL URI1 (Mean ± SD mm)†	7.29 ± 0.57		7.09 ± 0.53	7.19 ± 0.55	7.18 ± 0.55		6.97 ± 0.52	7.05 ± 0.54
MD URM1 (Mean ± SD mm)‡	10.59 ± 0.52		10.44 ± 0.49	10.51 ± 0.50	10.57 ± 0.55		10.42 ± 0.50	10.48 ± 0.52
BL URM1 (Mean ± SD mm)§	10.38 ± 0.56		10.13 ± 0.52	10.25 ± 0.54	11.29 ± 0.56		10.97 ± 0.49	11.09 ± 0.53
Presence of Shovel Trait (%)	91.74		78.33	84.72	93.86		83.08	87.06

*MD URI1: Mesiodistal diameter of upper right central incisor. SD: standard deviation.
†BL URI1: Buccolingual diameter of upper right central incisor.
‡MD URM1: Mesiodistal diameter of upper right first molar.
§BL URM1: Buccolingual diameter of upper right first molar.

shovel trait is associated with Carabelli's trait. An upper and lower 95% confidence limit of odds risk not containing the value of one was defined as a significant odds risk.

Results

More than half (56.31%) of the Chinese sample and (56.77%) of the Bunun aboriginal sample were male subjects. Regardless of gender, 36.89% of all the Chinese and 47.60% of all the Bunun aborigines showed signs of Carabelli's trait in the upper right first molars. Among the males, 50% of the Chinese and 62.31% of the Bunun aborigines showed signs of this traits. However, among the females, only 20.00% of the Chinese and 28.28% of the Bunun aborigines had the trait. The means and proportions of confounding variables of teeth with vs. without Carabelli's trait for each population are shown in Table 1. Significant dimorphism was found between males and females for Carabelli's trait in each population. Males were significantly more likely to show signs of Carabelli's trait than females ($p < 0.001$) in each population. No age difference was observed between presence and absence of Carabelli's traits in either Chinese or Bunun aboriginal population, although this factor may be reconsidered if studying groups with wider age variation.

Tables 1 and 2 show the possible confounding variables that were controlled for in the analysis. Regarding tooth size of the upper right first molars, the total studied sample had mean ± standard deviation of mesiodistal and buccolingual diameters of 10.48 ± 0.52 mm and 11.09 ± 0.53 mm, respectively. On the other hand, the Bunun aboriginal sample had those of 10.51 ± 0.50 mm and 10.25 ± 0.54 mm, respectively. After controlling for the confounding variables, the mean buccolingual diameter of the tooth with Carabelli's trait was significantly larger than that of the tooth without Carabelli's trait ($p < 0.05$) in each population. Furthermore, the mean mesiodistal diameter of the tooth with Carabelli's trait was slightly larger than that of the tooth without Carabelli's trait, but it was not statistically significant after adjusting for sex, age, and buccolingual diameters. Similarly, after adjustment, no statistically significant difference in the tooth size of the upper right central incisors was found between teeth with and without Carabelli's traits in either population.

Among the Chinese population, 39.78% subjects with shovel trait and only 17.50% subjects with no shovel trait showed signs of Carabelli's trait. However, among the Bunun aborigines, 51.55% subjects with shovel trait and 25.71% subjects with no shovel trait showed signs of Carabelli's trait. Compared to those without shovel trait, Chinese with the shovel incisor (odds risk, 5.99; 95% confidence interval, 2.54−14.13; $p < 0.001$) were more likely to have the Carabelli's trait molar as seen in Table 3. In contrast, compared to those without shovel trait, Bunun aborigines with the shovel incisor (odds risk, 3.15; 95% confidence interval, 1.44 ~ 6.92; $p < 0.001$) were more likely to have the Carabelli's trait molar.

TABLE 2—*Estimates and standard errors according to race in multivariate logistic regression: Carabelli's trait vs. no Carabelli's trait.*

Characteristics	Log odds			
	Bunun		Chinese	
	Estimate	Standard Error	Estimate	Standard Error
Sex	1.61¶	0.31	1.19¶	0.35
Age (years)	−0.21	0.17	−0.39	0.32
MD URI1 (mm)*	0.29	0.26	0.41	0.35
BL URI1(mm)†	0.36	0.28	0.52	0.43
MD URM1 (mm)‡	0.40	0.36	0.64	0.40
BL URM1 (mm)§	0.68‖	0.30	1.05‖	0.44
Presence of Shovel Trait	1.15¶	0.40	1.79¶	0.45

*MD URI1: Mesiodistal diameter of upper right central incisor.
†BL URI1: Buccolingual diameter of upper right central incisor.
‡MD URM1: Mesiodistal diameter of upper right first molar.
§BL URM1: Buccolingual diameter of upper right first molar.
‖$p < 0.05$, ¶$p < 0.001$. Significant difference between with and without Carabelli's trait measurements in the same race.

TABLE 3—*The comparative association between shovel and Carabelli's traits* (C.T.) *according to population group**.

Categories	Bunun		Chinese	
	C.T. vs. No C.T. N = 109 vs. 120		C.T. vs. No C.T. N = 114 vs. 195	
Shovel Trait	100	94	107	162
No Shovel Trait	9	26	7	33
Odds Risk	3.15		5.99	
95% Confidence Interval	1.44–6.92		1.54–14.13	
p	<0.001		<0.001	

*Statistic significance was determined by logistic regression controlling for the effects of sex, age, as well as both mesiodistal and buccolingual diameters of upper right central incisors and upper right first molars in the same race.

Discussion

According to previous studies, quasi-continuous or continuous variables have been used to treat nonmetric dental traits. Generally, the real trait expression intervals have been unequally categorized into several groups, but equally continuous intervals have been assumed to use in the prior analyses. However, the misclassification percentages found in several methods of dental trait classification have ranged from 22% to 56% (28). Furthermore, different authors use different standards to classify Carabelli's traits. For instance, the "pit" feature has been given different values or degrees in different classification systems. Some investigators have categorized "groove" and "cusp" as independent groups, others have had groups for "cusp" in contact with "groove" or "cusp" with no contact. Therefore, another method, assuming the threshold mechanism, has dichotomized the nonmetric dental traits into present and absent groups to view dental traits as entities (7,29,30). On the basis of these prior studies, dichotomization according to presence or absence of the dental traits better reduces possible classification bias.

Carabelli's trait is found to be sexually dimorphic in our Chinese and aboriginal populations. Similar dimorphism has been found elsewhere (14,15), but these findings are in contradiction with some other investigations (16,17). To conclude that sex differences exist in Carabelli's trait is difficult. Nevertheless, it may be noted that these prior studies are not exactly comparable because they differ in sample sizes and methods of analysis. The influence of possible confounding variables such as mesiodistal and buccolingual diameter in the right upper first molars or the right upper central incisors has seldom been considered. These methodological deficiencies in other studies may have led to contradictory findings. Therefore, we chase to use multivariate methods in our own analysis, which then identified the existence of significant sexual difference in these two populations.

For Chinese and aboriginal populations, after controlling for sex and age, significant differences are present in buccolingual diameters, but not in mesiodistal diameters of the right upper first molars. Such differences have been observed elsewhere (19,31,32). De Terra (31) and later Dahlberg (32) proposed that Carabelli's cusp is an adaptation that enlarged the occlusal surface of the first molars in the buccolingual dimension to compensate for evolutionary reduction in the length (mesiodistal diameter) of the maxillary molar row. Besides, it is believed that Carabelli's cusp is associated with larger first molars overall, and not especially with an increase in the buccolingual diameter. The opinion from the evolutionary perspective has been that Carabelli's trait might be a primitive structure that tends to disappear with molar reduction in all hominoid evolutionary lines (19,33). To explain the existence of Carabelli's trait, a functional proposal has been that it may be a structure that resists excessive biomechanical stresses on the first molar (34). Our results show that smaller first molars tend to have fewer occurrences of Carabelli's traits, and we believed that developmentally, Carabelli's trait is a disappearing structure in these two Mongoloid populations as their first molars get smaller. That Carabelli's trait serves a structural function needs additional biomechanical experimentation to be substantiated.

According to previous studies (5,6,41,58), shovel trait exists almost universally, and exists particularly frequently in Chinese, Taiwan aborigines, Eskimos, American Indians, and Australian aborigines. However, Carabelli's trait is less commonly found in these populations (4). Contrarily, populations derived from Europe have a low prevalence of shovel trait and a high prevalence of Carabelli's trait (4,23,35,36). The literature shows that Mongoloid, such as Chinese and Taiwan aborigines, as well as Caucasoid population frequencies differ remarkably in the expression of shovel trait on the upper right central incisor teeth and Carabelli's trait on the upper right first molars (4,37). Subsequently, shovel and Carabelli's traits have been viewed as dental markers of Mongoloid and Caucasoid origin. Knowing the real interaction between these two prominent dental markers in different races is therefore of forensic, biological, and anthropological importance for ethnic identification.

Comparatively, little attention has been paid to the outcome of multivariate analyses of the relation between shovel and Carabelli's traits, though many papers have examined dental traits in Chinese and aboriginal populations (4,23,30,38). By comparing the Chinese with the Taiwan aborigines, we show that after adjustment, the presence of the shovel trait tends to increase the likelihood of Carabelli's trait in these two Mongoloid populations. Moreover, the association between shovel and Carabelli's traits is more prominent in the Chinese than in the aboriginal population, and such an association might be assumed to be population specific. The positive association between the shovel and Carabelli's traits after proper data adjustment in the present study is similar to the positive association between these two dental markers in a Bunun aborigine population in the report by Tsai et al., who used a similar analytical method (7). In that report, they anticipated an analogous developmental relationship between shovel and Carabelli's traits. Subsequently, our present study may provide further evidence to support an analogous developmental relationship between these two dental traits. Moreover, the hypothesis that there is a positive association between these two dental traits common among the Mongoloid populations needs further research and verification. Additionally, the developmental relationship between shovel and Carabelli's traits found in the Mongoloid population may not be the same as that found in the Caucasoid population.

Explanatory models, including genetic and environmental factors for the manifestation of Carabelli's trait, have been described without considering its relationship to shovel trait (14,36). Besides the environment, Tsai et al. described that genes play a major role in the association between Carabelli's and shovel traits (7). Therefore, our findings may be explained by similar hypothesis. However, this assumption also needs to be tested with further family studies. Although the generalization of the intensity of the effect of shovel trait on Carabelli's trait seen in these two populations to other populations may be restricted, this study does facilitate and confirm a method of investigating the association between shovel and Carabelli's trait entities in other populations.

Conclusion

Both Taiwan Chinese and Bunun aboriginal populations had a higher frequency of shovel incisors and a lower frequency of Carabelli's trait molars than Caucasoids. Furthermore, these forensically anthropological findings were more remarkable among Taiwan Chinese population than among aboriginal population. The positive effect of shovel trait on Carabelli's trait was found in these two Mongoloid populations and the stronger positive effect was more evident among Taiwan Chinese than the Bunun aborigines.

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