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Craniometric Variation Among Medieval Croatian Populations

Derinna Vivian Kopp
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Derinna Vivian Kopp entitled "Craniometric Variation Among Medieval Croatian Populations." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Richard L. Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Lyle W. Konigsberg, Lee Meadows Jantz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew

Vice Provost and Dean of
Graduate Studies

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Craniometric Variation Among Medieval Croatian Populations

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Derinna Vivian Kopp

August 2002

DEDICATION

This thesis is dedicated to my parents, Richard and Donna Kopp, for your unconditional support in all I have done and for instilling in me a love for learning, and to my sisters, brothers, and all the wee ones in my family for always believing in and encouraging me, and for showing me that together we can get through anything.

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ABSTRACT

The purpose of this study is to examine craniometric variation among a series of medieval Croatian skeletons to determine if the populations inhabiting the coastal (Dalmatian) and continental (Pannionian) regions are morphometrically dissimilar. Differing historical population movements in the regions provide possible evidence for genetic, ethnic, and cultural dissimilarity between the Dalmatian and Pannionian regions. Cranial measurements from three coastal and three continental medieval Croatian sites are subjected to multivariate analyses to assess craniometric variation among the groups. Canonical variates analysis and distance matrix comparisons are completed for male and female mean data separately.

Plots of the first two canonical axes derived from the canonical variates analysis reveal no clear distinction between the coastal and continental sites for either sex. The plot of the male data does indicate a distinction between the late medieval site of Nova Raća and the other earlier Croatian sites. This dissimilarity is likely a result of not only temporal differences, but also increased ethnic diversity in the population of Nova Raća from intensified migrations of other central European peoples into the region beginning in the twelfth century.

Matrix comparisons of biological distance with geographic and temporal distances indicate that there is no significant correlation between any of the matrix pairs for both male and female data. Fairly high F_{st} values estimated from **R** matrices, however, indidcate genetic heterozygosity (differentiation) between the populations.

Based on these analyses it is suggested that there is differentiation between the groups studied, but no significant patterning between the coastal and continental populations of medieval Croatia.

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CHAPTER 1

Introduction

The study of variation in human groups is central to anthropological enquiry. In the subfield of physical anthropology, genetic and phenotypic variation has been used to assess population dynamics relative to evolutionary, historical, environmental, and cultural influences. The study of variability in past populations typically involves the use of genetic, metric, and/or non-metric traits collected from skeletal remains.

Biological distance (biodistance) analyses use skeletal traits to assess the amount of variation between and within populations. Craniometric data have regularly been used to quantify and assess variation within and among archaeological human groups (e.g. Howells 1973, 1989; Sokal et al 1987). Following the principle that morphological and metric (phenotypic) similarity implies genetic similarity, these studies employ multivariate statistical analyses to determine metric differentiation and variation among the study populations to evaluate genetic, evolutionary, cultural, and/or historical relationships (Buikstra et al. 1990; Jantz 1994).

The purpose of this study is to investigate craniometric variation in a series of medieval Croatian skeletons to test the hypothesis that coastal (Dalmatian) and continental (Pannonian) populations will be morphometrically distinct. The history of the region provides possible evidence for this differentiation. The medieval period was one of great demographic change in the Balkans, resulting from large-scale invasion, migration, and forcible transplantation of populations (Fine 1983). Most of the major cities in the early middle ages were seaports along the Adriatic. Along the Dalmatian Coast, there was clear ethnic and cultural separation between the pre-Slavic Romanized populations of the walled cities from that of the newer Slavic populations in the hinterland (Fine 1983). Inland, the continental Croatian towns did not see major growth until the late middle ages. Populations of this region, separated from the coast by the Dinaric Mountain Range, were most affected by an influx of peoples from the interior and areas east of the Danube including Avars, Ostrogoths, Magyars, and Germans.

The question examined here is whether or not the various historical population movements in this region will be expressed morphometrically between coastal and continental populations. Šlaus (1998) indicates that discriminant function analysis of site means for males from several eastern European countries reveals a distinction between medieval Croatian sites from the Dalmatian Coast and continental Croatian sites. This analysis will use craniometric data from three coastal and three continental medieval Croatian sites to examine the variability in the medieval Croatian population. Canonical variates analysis and distance matrix comparisons will be employed to assess variation among the groups. Additionally, **R** matrices will be derived for each sex and F_{st} values will be estimated from the matrices to provide estimates of population heterozygosity.

Chapter 2 will review the methods used by anthropologists to examine population structure and variability using human skeletal remains. Craniometric analyses will be surveyed with close attention paid to medieval and Croatian studies. A brief history of Croatian population dynamics will be discussed to provide a background for inquiry into the biological composition of medieval populations inhabiting the lands. The samples and methods used in this analysis will be described in Chapter 3, with the results of the analysis presented in Chapter 4. Discussion and conclusions of the analysis will be presented in Chapter 5.

CHAPTER 2

Literature and History Review

Biological Distance and Past Populations

Variation within and between archaeological and contemporary populations can be assessed with skeletal data using computations of biological distance. Biological distance or biodistance is "the measurement and interpretation of relatedness or divergence between populations or subgroups within populations based on the analysis of polygenic skeletal or dental traits" (Larsen 1997:302 after Buikstra et al. 1990). Biodistance analyses examine metric and nonmetric variation in the shape and form of skeletal elements to distinguish patterns that are believed to reflect genetic relationships (Buikstra et al. 1990). Populations or subpopulation groups sharing high or low frequencies of specific morphological (phenotypic) characteristics are considered to have a higher degree of relatedness and closer biological affinity (Larsen 1997).

Skeletal traits are influenced by both genetic and environmental factors, subsequently complicating the use of such traits as proxies for genetic data in biodistance analysis. Consequently, as Buikstra and colleges (1990) have noted, some researchers have questioned the use of skeletal traits for biodistance analyses because the heritability of the skeletal phenotypes is unknown. However, several studies have shown that anthropometric and craniometric results are comparable to quantitative genetic data (see Williams-Blangero and Blangero 1989; Harding 1990; Relethford 1994; Konigsberg and

Ousley 1995). Using Howells'(1973) data, Relethford (1994) used analyses based on population genetics theory to estimate the among-group variation, F_{ST}, for comparison with genetic studies. The results indicated that craniometric data are comparable both qualitatively and quantitatively to genetic data (Relethford 1994). Subsequent studies have successfully used anthropometric and craniometric data to estimate genetic heterozygosity of populations and to examine population structure and differentiation (see Relethford 1994; Relethford and Crawford 1995; Wescott and Jantz 1999; Tatarek and Sciulli 2000).

Multivariate statistical analysis is typically used to identify and examine biological relationships between and within populations. Statisical methods employed include principal components analysis, discriminant function, biodistance statistics (i.e. Mahalanobis' distances, D^2 generalized distances, and C-scores and Q-mode analysis of C-scores), and cluster analysis (Larsen 1997).

Studying biological distances between past populations is an important aspect of physical anthropology (Buikstra et al. 1990). In particular, questions of evolutionary history can be addressed using both historic and contemporary populations (Sokal and Uytterschaut 1987; Harding et al. 1989). In addition, group movement and residence patterns of archaeological populations can be ascertained using biological variation studies (see Kennedy 1981; Konigsberg 1988; Konigsberg and Buikstra 1995). Biological distance analyses are also useful in tandem with paleopatholgical and paleodemographic data (Buikstra 1977; Buikstra et al. 1990).

Craniometric Analyses

Craniometric traits have been central to biodistance studies, which examine inter- and intra-population variation in archaeological populations. These analyses have examined differentiation and variation of populations in various geographical and temporal contexts. Studies of world-wide population variation have been conducted by Howells (1973), Relethford (1994), Relethford and Harpending (1994), and Hanihara (1996). Similarly, regional population variation has been examined (i.e. Sokal et al. 1987; Rothhammer and Silva 1990; Hanihara 1993; Powell and Neves 1999; Šlaus 1998, 2000b; Jantz and Owsley 2001). Variation at localized sites or within relatively small geographical areas has also been attempted using craniometric analyses (Šlaus 1993; Byrd and Jantz 1994; Jantz and Owsley 1994; Key 1994; Fox et al. 1996; Stefan 1999).

Howells' (1973) investigation of cranial variation in human populations indicated the existence of "…morphological patterns or subpatterns differentiating actual populations" (Howells 1973:151), and considerable similarity was found among populations from the same geographic regions. In this and subsequent studies, Howells (1989, 1995) showed substantial craniometric similarities in local regional populations and differences between regional populations.

Researchers have also used craniometric analyses to assess temporal and geographic variation between and within groups. Sokal and colleagues (1987) and Sokal and Uytterschaut (1987) specifically addressed variation among European populations from three time periods. Using sample means from Early Medieval, Late Medieval, and contemporary time periods, Sokal et al. (1987) demonstrated significant cluster associations by geographic region and language family. For all three time periods, geography proved to be more strongly correlated with cranial morphology than language, but with time, the language correlation became stronger. Similarly, when pooled, the populations group more by language family than by time period (Sokal et al. 1987). Sokal and Uytterschaut's (1987) study of spatial variation of the cranial variables from the same sites and time periods revealed similar results. Significant spatial variation and regional patterns that became more defined with time were found for most variables (Sokal and Uytterschaut 1987). The authors indicate that the patterns found in both of these studies are likely the result of migration and expansion of populations rather than *in-situ* geographic differentiation (Sokal et al. 1987; Sokal and Uytterschaut 1987).

Šlaus (1998, 2000b) assessed craniometric variation among medieval Central/Eastern European populations to examine possible routes for Croat population expansion in the Middle Ages. In the first of Šlaus' studies, mean values for eight cranial variables from 39 sites were subjected to principal component and discriminant function analyses to determine the relationships between the groups (Šlaus 1998). The sites used in this study were from present day Austria, Bosnia and Herzegovina, Croatia, the Czech Republic, Hungary, Poland, Slovenia, and Yugoslavia. The craniometric distribution revealed a geographical pattern in which Hungarian Avaroslav sites west of the Danube clustered together as did the Hungarian and Yugoslav Avaroslav sites east of the Danube. Slav sites from Austria, the Czech Republic, and Slovenia clustered together, and the Polish sites grouped together (Šlaus 1998).

Discriminant function analysis of the Croatian and Bosnian sites revealed a distinction between Croatian sites from the Dalmatian Coast and the Bosnian sites from continental Croatia. The four Dalmatian sites and the two Bosnian sites were classified with the Polish sites, while the two Avaroslav continental Croatian sites classified with the Hungarian Avaroslav sites west of the Danube. The other two continental Croatian sites near Vukovar classified with the Slav sites (Šlaus 1998). Šlaus used this data to hypothesize a possible route taken by early migrants to populate the modern Croatian landscape. He hypothesized that the traditionally Slavic peoples migrated to the Dalmatian Coast from an area in modern Poland. These migrants then gradually expanded into the continental lands of present day Bosnia by the tenth century, but had not expanded as far north as the Vukovar region by the end of the eleventh century (Šlaus 1998).

Šlaus also examined Croat expansion from the tenth to thirteenth centuries, using craniometric data from medieval sites in Austria, Bosnia and Herzegovina, Croatia, the Czech Republic, Hungary, and Slovakia (Šlaus 2000b). The sites grouped into four distinct clusters: Avaroslav groups west of the Danube, Avaroslav groups east of the Danube, the Bijelo Brdo culture populations, and Croatian populations. Šlaus argued that the geographic and temporal distribution of the sites indicates a north to south migration of groups into the Dalmatian Coast. These groups subsequently expanded inland into the regions of present day Slovenia and Bosnia and Herzegovina (Šlaus 2000b).

Croatian History

Šlaus' studies identified craniometric variation in the medieval populations of contemporary Croatia. Differentiation was the greatest between the Dalmatian Coast and continental sites. The history of the region provides possible explanations for these differences. Medieval peoples inhabiting coastal and continental Croatia are believed by most scholars to be of mainly Slavic descent (Guldescu 1967; Fine 1983; Magocsi 1993). The Slavic peoples, however, were not the initial inhabitants of the region. Three indigenous populations (Illyrians, Thracians, and Dacians) are believed to have originally occupied the lands north of modern day Greece. The Illyrians inhabited the areas of Dalmatia, Istria, Epirus, northwestern Macedonia, Bosnia, Herzegovina, and western Serbia. The Thracians lived in Thrace (present day Bulgaria and eastern Macedonia), and the Dacians inhabited areas of northern Bulgaria, Romania (Dacia), and northeastern Yugoslavia (Fine 1983). Prior to the Slavic invasions of the late sixth and early seventh centuries, the Balkan region was an important part of the Roman Empire. The Roman Empire expanded into the Balkans beginning in the second century B.C. and by the first century AD was well established in Dalmatia (Fine 1983). The Roman influence in Dalmatia was so significant that the major port cities of the area would remain Italian in character throughout the Middle Ages.

During the first century AD, the Romans began moving inland from the Adriatic coast toward the Danube. However, other than forts and small towns connected by roads, the majority of the region was still populated by indigenous peoples (Fine 1983). With the creation of Constantinople as the capital of the Empire, the Balkans were split among three prefectures, and the regions of Pannonia, Istria, and Dalmatia (much of present day Croatia) became part of the Italian Prefecture (Fine 1983; Magocsi 1987). This segmentation maintained the Italian influence over the coastal and Pannonian regions.

In the mid-sixth to early seventh centuries, the Slavs began raiding and invading the Pannonian area of the Balkans, from areas east of the Danube. The seventh and eighth centuries were marked by the dispersal of the Slavs throughout the Balkans and the arrival of the Avars from the east (Magocsi 1993). The western regions first settled by Slavs, including much of present day western Bosnia, Dalmatia, and Croatia, suffered multiple Avar raids. The extent of Avar settlement in the regions is not clear and the issue is debated by archaeologists and historians (Fine 1983). The Avar offensives into the western lands resulted in some of the territory coming under direct Avar control by the second decade of the seventh century. Fine (1983) reports several revolts against the Avars from AD 620 to about AD 640. One of the major uprisings was that of the Serbo-Croatians, which liberated much of the western Balkans from the Avars.

The Croats and Serbs appear to have arrived in the Balkans in the early to mid-seventh century from what are generally believed to be Iranian origins (Guldescu 1967; Fine 1983). The arrival of the Croats and Serbs followed that of the Slavs and Avars, and according to the classical source Constantine Porphyrogenitus, the Croats and Serbs expelled the Avars, subjugated the Slavs, and were then assimilated by the Slavic peoples by the late eighth century (Fine 1983). The Slavic peoples that settled most of the Balkans came to be considered as two groups, the Bulgaro-Macedonian Slavs and the Serbo-Croatian Slavs, named for traditionally non-Slavic peoples who conquered the

Slavs in the seventh century and were then assimilated by the Slavic populations (Fine 1983). The Bulgaro-Macedonian Slavs inhabited the region of the lower Danube, while the Serbo-Croatian Slavs settled in the Adriatic and western Pannonian regions.

The Croats and Serbs organized into tribal federations that would serve as the nuclei for the future Croatian and Serbian states (Magocsi 1993). The regions of Dalmatia and Pannonia were established as separate Croatian states. The ninth century brought Frankish overlords to both Pannonian and Dalmatian Croatia. The Frankish rule would last for most of the ninth century, but few if any Franks actually settled in the regions (Fine 1983). While the two regions were officially under Frankish authority, each also had a native ruling prince. With the end of Frankish control, each region established independent states (Guldescu 1967; Fine 1983), which were subsequently united in the tenth century under Tomislav, the first Croatian king.

Hungary annexed the unified Croatia early in the twelfth century, and the union of the two became known as Hungary-Croatia (Fine 1983; Magocsi 1993). The merger with Hungary brought many changes to the Croatian lands, especially in the Pannonian region centered around the Sava River. This region, which is contemporary continental Croatia, came to be called Slavonia in the Hungarian-Croatian union. In this region, trade with Hungary and other states spurred the development of towns, and the growth of a merchant class brought new peoples to the area including Hungarians, Germans and Jews (Fine 1987). The Dalmatian port cities continued close interactions with Italian cities and many were ruled intermittently by Venice through the fifteenth century (Magocsi 1993). The fifteenth and sixteenth centuries saw the encroachment of the Ottoman Empire into the southern lands of Hungary-Croatia, and the Habsburg Empire moved into the northern lands. During this time, Habsburgs encouraged resettlement of the Danubian basin resulting in greater ethnic diversity in the area, especially in the Hungary-Croatia region of Slavonia (Magocsi 1993).

CHAPTER 3

Materials and Methods

This study will test the hypothesis that skeletal populations from the Dalmatian Coast and Pannonian (continental) regions of medieval Croatia are differentiated morphometrically. Craniometric data from coastal and continental populations will be used to examine the variation among and within medieval Croatian populations. Canonical variates analysis, matrix comparisons, and F_{st} estimated from **R** matrices will be used to assess the relationships among the groups.

Materials

The data consist of cemetery burials dating from 650 to 1700 AD. The coastal sites include Radasinovac and Korlat from the Zadar region, and Danilo and Dubravice from the Šibenik province. The continental sites include Nova Raća, which is located in central Croatia, and Stari Jankovici and Privlaka located in eastern Croatia. Figure 1 shows the location of each site on a map of present day Croatia. The data for this study were obtained by two researchers. Cranial measurements from the sites of Danilo, Stari Jankovici, Nova Raća, and Privlaka were collected and provided by M. Šlaus, and the data from the sites of Radasinovac, Korlat, and Dubravice were collected by the author. Measurements taken by the author used standard anthropometric instruments following Howells (1973). The metric data provided by Šlaus follow Howells (1973) and

Figure 1. Map of Croatia with study locations identified.

comparable standards defined by Martin (1956). Table 1 summarizes the samples used in this study.

Coastal Data:

Radasinovac and Korlat are located in the Zadar region and are within walking distance of each other (Šlaus personal communication), and for this reason, the data will be pooled for analysis. The sites were excavated by R. Jurić of Zadar University, and the skeletal remains are housed at the Archaeology Museum in Zadar, Croatia. The archaeological report for the sites remains unpublished. The cemeteries were used from 800 to 900 AD (Šlaus personal communication). The data from these two sites consists of cranial measurements obtained from ten individuals; four females and six males. The author collected the measurements in May 2001 at the Archaeology Museum in Zadar, Croatia with permission of museum officials. Only adults over 18 years of age were included in this analysis. Sex estimation was based on pelvic, cranial, and postcranial morphology. Age was determined using pubic symphysis morphology, sternal rib end morphology, and cranial suture closure.

The cemetery of Dubravice is located in the Šibenik province. The cemetery was in use between 700 and 900 AD (Šlaus personal communication). The site was excavated by Z. Gunjča, and the archaeological findings for the site remain unpublished. Data for Dubravice include cranial measurements from ten adults including three females and seven males. The age and sex estimates of the ten individuals were based on pelvic and cranial morphology. The data were collected by the author (in May 2001) with the

Table 1. Samples used in the study.

Sample	Date	Male	Female	Total	Reference
Coastal					
Danilo (DA)	900-1500 AD	5	7	12	Šlaus 1998
Dubravice (DB)	700-900 AD	7	3	10	Current study
Radasinovac/Korlat (RD/KR)	800-900 AD	6	4	10	Current study
Continental					
Nova Raća (NR)	1300-1700 AD	7	4	11	Šlaus 2000a
Privlaka (PV)	750-850 AD	17	10	27	Šlaus 1996
Stari Jankovci (ST)	650-750 AD	5	7	12	Šlaus 1997

permission of Dr. M. Šlaus at the Croatian Academy of Sciences and Arts in Zagreb, Croatia.

The Danilo site is also located in Šibenik province, and use of the cemetery dates from 900 to 1500 AD (Šlaus 1998). Cranial measurements from twelve adults, which include seven females and five males, were collected by Dr. M. Šlaus and provided to Dr. R.L. Jantz, University of Tennessee, for study.

Continental Data:

Nova Raća is located in central Croatia, approximately 75 km east of Zagreb. The cemetery was used from 1300 to 1700 AD. M. Šlaus collected and provided the craniometric data from Nova Raća for eleven individuals, including four females and seven males, to Dr. R.L. Jantz.

The Stari Jankovici and Privlaka cemeteries are located in eastern Croatia, south of the town of Vukovar. The Stari Jankovici cemetery was used from 650 to 750 AD, and Privlaka dates from 750 to 850 AD. Both sites are considered to be late Avaro-Slav sites based on archaeological findings, with Privlaka defining the southern boarder of the Avar kingdom (Šlaus 1996, 1997). The Stari Jankovici data includes cranial measurements from twelve adult individuals that consist of seven females and five males. The Privlaka data includes twenty-seven individuals consisting of ten females and seventeen males. The data from Stari Jankovici and Privlaka were collected by M. Šlaus and provided to Dr. R.L. Jantz.

Methods

When the primary data set was examined for missing values, it was apparent that a number of measurements were missing. In most cases the number of missing values was too great for statistical estimation of the values, and estimation of missing values was not attempted. The extent of missing data, along with the already small sample sizes for some of the sites precluded the use of the raw measurements for the analysis. Consequently, mean values for each measurement were calculated by sex and site and used for the study.

Ten standard cranial measurements were used in this analysis to examine craniofacial variation among medieval Croatian populations. The measurements used in this study and their definitions are listed in Table 2. Due to missing values, the analysis of the male data used 10 measurements (GOL, BNL, BBH, XCB, ZYB, BPL, NLH, NLB, OBH, and OBB) and analysis of the female data used 7 measurements (GOL, BBH, XCB, NLH, NLB, OBH, and OBB). Canonical variates analysis and distance matrix comparisons were used to assess the data. Each statistical analysis was completed for males and females separately.

To minimize the effects of small sample size and missing values on the analysis, and to allow the use of means, a pooled within-groups covariance matrix was generated using two of Howells' populations from Central Europe (1973, 1989, 1995). The Zalavar and Berg data sets were chosen because of their proximity to the study locations. The Zalavar sample comes from cemeteries in the town of Zalavar in western Hungary, and

Table 2. Definitions of cranial measurements.

Measurement	Definition	Reference
Maximum Cranial Length (g-op, GOL)	The distance of Glabella (g) from Opisthocranion (op) in the mid sagittal plane measured in a straight line.	Howells 1973:170; Martin 1956:453 #1
Cranial Base Length (ba-n, BNL)	The direct distance from nasion (n) to basion (ba).	Howells 1973:171; Martin 1956:455 #5
Basion Bregma Height (ba-b, BBH)	The direct distance from the lowest point on the anterior margin of the foramen magnum, basion (ba), to bregma.	Howells 1973:172; Martin 1956:459 #17
Maximum Cranial Breadth (eu-eu, XCB)	The maximum width of the skull perpendicular to the mid sagittal plane wherever it is located with the exception of the inferior temporal line and the immediate area surround the latter (i.e. the posterior roots of the zygomatic arches).	Howells 1973:172; Martin 1956:455 #8
Bizygomatic Breadth (zy-zy, ZYB)	The direct distance between each zygion (zy), located at the most lateral points of the zygomatic arches.	Howells 1973:173; Martin 1956:476 #45
Basion Prosthion Length (ba pr, BPL)	The direct distance from basion (ba) to prosthion (pr).	Howells 1973:174; Martin 1956:474 #40
Nasal Height (n-ns, NLH)	The direct distance from nasion (n) to nasospinale (ns)	Howells 1973:175; Martin 1956:479 #55
Nasal Breadth (al-al, NLB)	The maximum breadth of the nasal aperture.	Howells 1973:176; Martin 1956:479 #54
Orbital Height (OBH)	The direct distance between the superior and inferior orbital margins.	Howells 1973:175; Martin 1956:478 #52
Orbital Breadth (d-ec, OBB):	The laterally sloping distance from dacryon (d) to ectoconchion (ec).	Howells 1973:175; Martin 1956:477 478 #51a

dates from the ninth to eleventh century AD. The Zalavar population was diverse and included Avar, Germanic, Slavic, and Magyar elements (Howells 1989). The Berg data was collected from eighteenth and ninteenth century charnel house remains from a small village in Carinthia, Austria, and is comprised primarily of individuals from about five generations in the village (Howells 1989).

The computer program NTSYSpc (Applied Biostatistics Inc. 2000) was used to generate the pooled within-group covariance matrix for the Zalavar and Berg data sets. That matrix was then used in conjunction with the Croatian site means, which were weighted by the sample size of the groups, to perform a canonical variates analysis in the CVA option of NTSYSpc (Applied Biostatistics Inc. 2000). Canonical variates analysis (CVA) is used to study the variation among two or more groups relative to the average variation found within the groups. The overall significance test for CVA is also the appropriate significance test for a single classification multivariate analysis of variance, MANOVA (Applied Biostatistics Inc. 2000). This program performs a principal components analysis (PCA) on the pooled within-groups covariance matrix, ignoring components whose eigenvalues are less than a specified cutoff, however, all componenets were retained for this analysis. This analysis examined the variation among the Croatian groups relative to the average variation found within the Berg and Zalavar populations. The results of the CVA analysis include generalized distance (D) between all pairs of groups and canonical scores for the groups. Eigenvalues and eigenvectors of both the pooled within-groups variance-covariance matrix and the standardized among-group variance-covariance matrix are also produced by this program. The canonical scores were plotted to graphically represent the relationships among the groups.

Matrix comparison correlations (Mantel tests) (Mantel 1967; Smouse et al. 1986) were then executed using the generalized biological (cranial) distances, geographical distances, and temporal distances to assess the relationships between the three. The generalized distances produced in the canonical variates analysis were used for biological distance matrix. Actual geographic distances between the sites were computed in kilometers for the geographical distance matrix. Temporal distances were obtained by computing the difference between site use dates using the mid-usage date for each site, and then squaring the differences.

Both 2-way comparisons and 3-way comparisons of the distance matrices were carried out. The 2-way test measures the association between the elements in two matrices using an appropriate statistic, and then assesses the significance of this statistic by comparison with the distribution found by randomly permutating the rows and columns in one of the matrices. The 3-way approach similarly tests the relationships between two matrices while controlling the effects of a third matrix. Two-way comparison correlations were performed for biological distances with geographic and temporal distance matrices. Correlations of biological distance with geographical distance controlling for time and with temporal distance controlling for geography were also executed.

Matrix comparisons for biological, geographic, and temporal distances were also performed using a binary geographic distance matrix where a zero (0) value was used to denote the distance between two coastal and/or two continental sites and 1 was used to denote the distance between coastal and continental sites. These comparisons serve as an eplicit test of the coastal-continental differentiation.

The matrix comparisons were performed using a computer program written by Dr. R.L. Jantz. For each comparison the biological distance matrix was permutated 999 times. The program computes the Pearson correlation (r), which is the same as a normalized Mantel statistic, for each comparison. The test of significance (P) for each comparison was obtained by dividing the number of random permutations that were greater than or equal to the observed correlation coefficient (r) by the total number of permutations of the biological distance matrix (1000 = 1+ number of permutations). Significance was determined at the 0.05 level.

Finally, the male and female generalized distance matrices were used to estimate an "**R**" matrix for each sex. The "**R**" matrix (Harpending and Jenkins 1973) is a variance-covariance matrix that estimates genetic distances from phenotypic data. It also provides estimates of F_{st}, or subpopulation heterozygosity in relation to total population heterozygosity. To produce minimum estimates of $F_{st,}$ genetic distances are often computed with heritability estimates of h^2=1. For elaboration of the **R**-matrix method see Harpending and Jenkins (1973) and Relethford and Harpending (1994).

Dr. Lyle Konigsberg, The University of Tennessee, Knoxville, provided a method to convert the generalized distance matrices to **R** matrices for each sex. The generalized distances (**D**) produced by NTSYSpc were first squared to produce $\mathbf{D^2}$ matrices. The $\mathbf{D^2}$

matrix was then used to calculate a "co-divergence" matrix, **C**. The **C** matrix is calculated as:

$$\mathbf{C} = -0.5(\mathbf{I}-\mathbf{1w}')\mathbf{D}^2 (\mathbf{I}-\mathbf{1w}')' ,$$

where **I** is a *g* by *g* identity matrix (*g* = the number of groups), **1** is a *g* by one column vector of ones, $\mathbf{D}^2$ is the squared distance matrix calculated on *t* traits (for males *t*=10 and for females *t*=7), and **w** is a *g* by one column vector of relative census sizes (sizes assumed equal for this study).

F_{st} is then calculated using results from Relethford and Harpending (1994) as:

$$F_{st} = \frac{\boldsymbol{w}' diag\{\boldsymbol{C}\}}{2t = \boldsymbol{w}' diag\{\boldsymbol{C}\}} ,$$

where *diag*{**C**} is an operator that places the diagonal of a matrix into the column vector. The **R** matrix is calculated as:

$$\mathbf{R} = \mathbf{C}\ (1-F_{st}) / 2t .$$

The average of the **R** matrix diagonal provides an estimate of minimum Fst for all groups.

CHAPTER 4

Results

Canonical Variates Analysis

To examine craniometric variation among a series of skeletons from three coastal and three continental medieval Croatian sites a canonical variates analysis was performed on means for 10 male (Table 3) and 7 female (Table 4) cranial measurements. The canonical variates analysis of the male means indicated that 80.3% of the among-group variation was accounted for by the first two canonical axes (Table 5). The bivariate plot of CAN1 and CAN2 is presented in Figure 2. It shows the clear distinction of Berg (BER) and Nova Raća (NR) from the other groups. However, no clear dissimilarity between the other coastal and continental groups is indicated. All of the remaining skeletal populations cluster with Zalavar and there is no apparent distinction between coastal and continental groups.

Analysis of the female means indicated that 79.2% of the among-group variation was described by the first two canonical axes (Table 6). The plot of the CAN1 and CAN2 (Figure 3) similarly reveals no distinct clustering of the groups, indicating no differentiation between coastal and continental groups.

Table 3. Male cranial measurement means.

Site	GOL	BNL	BBH	XCB	ZYB	BPL	NLH	NLB	OBH	OBB
ZAL	180.3	98.5	130.3	147.6	135.5	93.7	51.7	25.5	33.7	40.1
BER	185.1	101.2	135.0	141.3	133.1	97.1	51.4	25.4	32.6	39.9
DA	184.8	102.6	137.8	143.2	132.5	98.3	49.5	26.0	31.5	40.3
DB	187.4	100.0	134.3	139.6	130.0	94.2	51.9	24.4	33.1	39.9
NR	179.9	100.5	131.8	145.0	136.9	92.7	50.0	26.2	34.2	38.3
PV	184.0	102.1	132.2	139.5	130.7	95.2	52.0	24.9	33.4	39.6
RD/KR	187.8	104.0	13.0	139.0	133.0	98.3	51.0	23.8	32.3	40.3
ST	183.6	103.7	136.0	139.8	131.4	98.0	50.0	26.1	31.3	40.3

Table 4. Female cranial measurement means.

Site	GOL	BBH	XCB	NLH	NLB	OBH	OBB
ZAL	176.4	128.7	136.8	48.5	24.6	32.1	38.6
BER	170.5	124.4	140.3	48.2	24.9	32.7	38.4
DA	180.6	129.4	135.7	48.8	25.4	33.0	38.4
DB	176.0	133.3	131.3	46.0	22.0	30.5	36.6
NR	167.3	133.5	129.0	44.6	22.0	31.6	38.0
PV	177.7	128.8	134.5	50.4	25.1	32.6	39.6
RD/KR	177.3	124.3	131.3	48.3	22.8	32.3	38.3
ST	173.0	129.5	134.8	47.0	23.4	34.6	37.3

Table 5. PCA of among-groups relative to within VCV matrix for males.

CAN	Eigenvalue	Percent	Cumulative
1	1.14243212	63.7937	63.7937
2	0.29571480	16.5128	80.3065
3	0.18507383	10.3346	90.6410
4	0.09378904	5.2372	95.8782
5	0.04723692	2.6377	98.5160
6	0.02291296	1.2795	99.7954
7	0.00366338	0.2046	100.0000

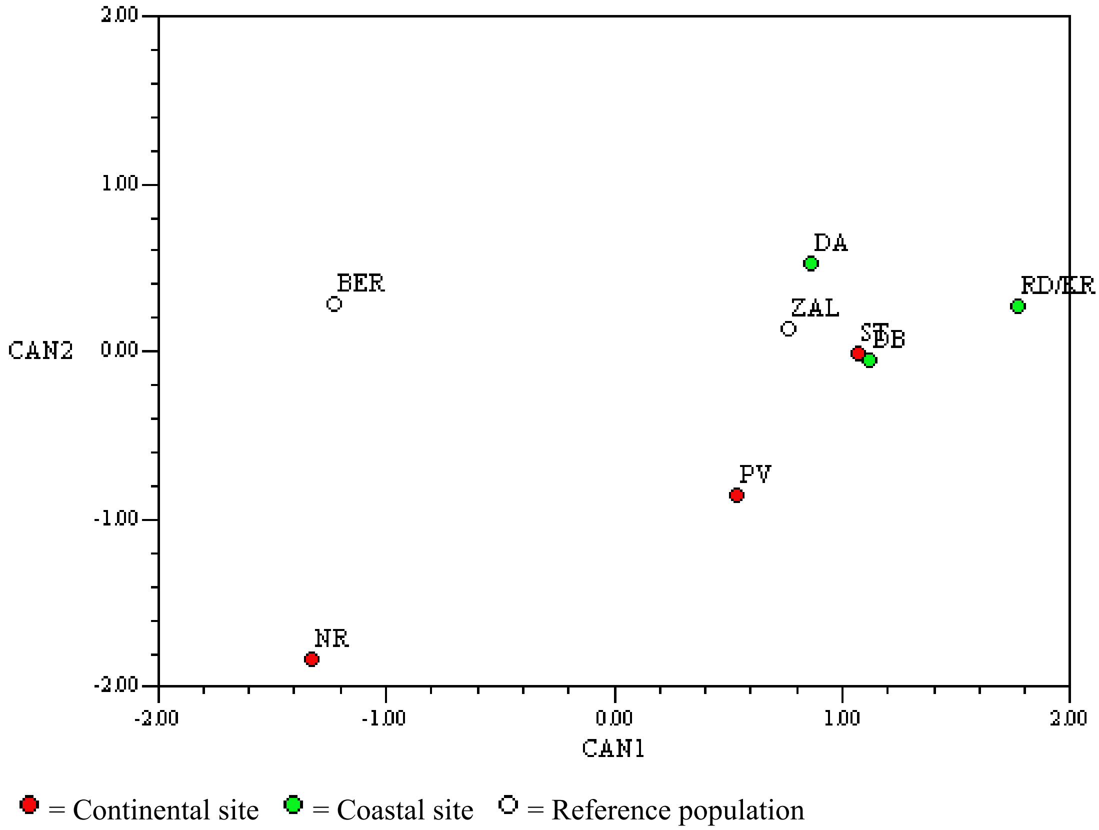
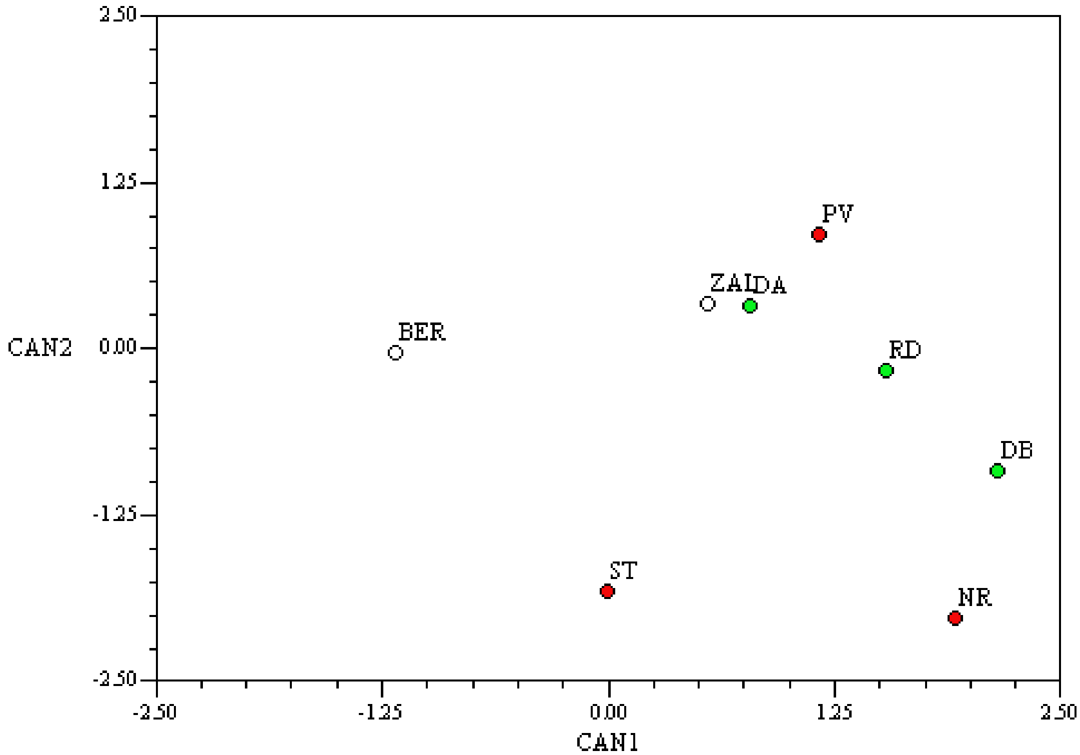


Figure 2. Plot of CAN1 and CAN2 for male means.

Table 6. PCA of among-groups relative to within VCV matrix for females.

CAN	Eigenvalue	Percent	Cumulative
1	1.31409212	60.0240	60.0240
2	0.42008674	19.1884	79.2123
3	0.21709430	9.9162	89.1286
4	0.13008189	5.9418	95.0704
5	0.09448494	4.3158	99.3862
6	0.01022586	0.4671	99.8533
7	0.00321273	0.1467	100.0000



= Continental site = Coastal site = Reference population

Figure 3. Plot of CAN1 and CAN2 for female group means.

Matrix Comparison

Two and 3-way matrix comparisons of biological (Tables 7 and 8), geographical (Table 9), and temporal (Table 10) distance matrices were completed with 999 permutations of the biological distances matrix. Additional 2-way and 3-way matrix comparisons were also completed using a binary distance matrix (Table 11), where distance between two coastal and/or two continental sites was zero (0) and distance between coastal and continental sites was one (1). The biological distance matrix was also permutated 999 times in these comparisons.

The matrix comparisons with actual geographic distance revealed no significant correlation, at the 0.05 level, between any of the matrix pairs for either male and female matrices (Tables 12 and 13). The comparisons using the binary geographic distance matrix similarly indicated no significant correlation at the 0.05 level for either sex (Tables 14 and 15). The correlation between male biological and binary geographical distance controlling for time has a P value of 0.057 (Table 14), an almost significant correlation at the 0.05 level and the most significant of all the correlations.

The derived **R** matrices (assuming heritability of 1.0) for males and females are presented in Tables 16 and 17. The average of the **R** matrix diagonal provides minimum Fst estimates for the populations (Table 18).

Table 7. Male Mahalanobis generalized distance (D).

	Danilo (DA)	Dubravice (DB)	Nova Raća (NR)	Privlaka (PV)	Radasinovac/ Korlat (RD/KR)	Stari Jankovci (ST)
Danilo (DA)	0					
Dubravice (DB)	2.02	0				
Nova Raća (NR)	3.41	3.52	0			
Privlaka (PV)	2.24	1.37	2.81	0		
Radasinovac/Korlat (RD/KR)	1.98	1.67	3.97	2.14	0	
Stari Jankovci (ST)	1.01	1.92	3.38	1.76	1.88	0

Table 8. Female Mahalanobis generalized distance (D).

	Danilo (DA)	**Dubravice (DB)**	**Nova Raća (NR)**	**Privlaka (PV)**	**Radasinovac/ Korlat (RD/KR)**	**Stari Jankovci (ST)**
Danilo (DA)	0					
Dubravice (DB)	2.84	0				
Nova Raća (NR)	3.49	2.45	0			
Privlaka (PV)	1.62	3.02	3.22	0		
Radasinovac/Korlat (RD/KR)	2.39	2.30	2.97	2.17	0	
Stari Jankovci (ST)	2.34	3.27	2.95	3.14	3.09	0

Table 9. Geographic distance matrix, distances in kilometers.

	Danilo (DA)	**Dubravice (DB)**	**Nova Raća (NR)**	**Privlaka (PV)**	**Radasinovac/ Korlat (RD/KR)**	**Stari Jankovci (ST)**
Danilo (DA)	0					
Dubravice (DB)	10	0				
Nova Raća (NR)	245	237	0			
Privlaka (PV)	275	280	160	0		
Radasinovac/Korlat (RD/KR)	57	50	220	270	0	
Stari Jankovci (ST)	285	290	165	10	280	0

Table 10. Temporal distance matrix, in $(years/100)^2$.

	Danilo (DA)	**Dubravice (DB)**	**Nova Raća (NR)**	**Privlaka (PV)**	**Radasinovac/ Korlat (RD/KR)**	**Stari Jankovci (ST)**
Danilo (DA)	0					
Dubravice (DB)	16	0				
Nova Raća (NR)	9	49	0			
Privlaka (PV)	4	0	49	0		
Radasinovac/Korlat (RD/KR)	12.25	0.25	42.25	0.25	0	
Stari Jankovci (ST)	25	1	64	1	2.25	0

Table 11. Binary geographic distance matrix, designating coast vs. continental.

	Danilo (DA)	**Dubravice (DB)**	**Nova Raća (NR)**	**Privlaka (PV)**	**Radasinovac/ Korlat (RD/KR)**	**Stari Jankovci (ST)**
Danilo (DA)	0					
Dubravice (DB)	0	0				
Nova Raća (NR)	1	1	0			
Privlaka (PV)	1	1	0	0		
Radasinovac/Korlat (RD/KR)	0	0	1	1	0	
Stari Jankovci (ST)	1	1	0	0	1	0

Table 12. Male distance matrix comparison results, using geographic distances.

Comparison	Correlation	P
Biological with geographical	0.08395	0.305
Biological with temporal	0.67254	0.126
Biological with geographical controlling for time	0.16001	0.181
Biological with temporal controlling for geography	0.69951	0.117

Table 13. Female distance matrix comparison results, using geographic distances.

Comparison	**Correlation**	**P**
Biological with geographical	-0.04766	0.493
Biological with temporal	0.13138	0.376
Biological with geographical controlling for time	-0.04913	0.494
Biological with temporal controlling for geography	0.12703	0. 392

Table 14. Male matrix comparisons with binary geographic distance matrix.

Comparison	Correlation	P
Biological with geographical	.06887	0.243
Biological with temporal	.67254	0.126
Biological with geographical controlling for time	.33153	0.057
Biological with temporal controlling for geography	.64772	0.102

Table 15. Female matrix comparisons with binary geographic distance matrix.

Comparison	Correlation	P
Biological with geographical	-.13353	0.725
Biological with temporal	-.27554	0.830
Biological with geographical controlling for time	-.15368	0.814
Biological with temporal controlling for geography	-.25921	0.846

Table 16. Male **R** matrix.

	Danilo (DA)	Dubravice (DB)	Nova Raća (NR)	Privlaka (PV)	Radasinovac/ Korlat (RD/KR)	Stari Jankovci (ST)
Danilo (DA)	0.0647	-0.0225	-0.0305	-0.0520	0.0024	0.0378
Dubravice (DB)	-0.0225	0.0715	-0.0833	0.0211	0.0311	-0.0178
Nova Raća (NR)	-0.0305	-0.0833	0.3120	0.0079	-0.1368	-0.0694
Privlaka (PV)	-0.052	0.0211	0.0079	0.0541	-0.0175	-0.0136
Radasinovac/Korlat (RD/KR)	0.0024	0.0311	-0.1368	-0.0175	0.1141	0.0068
Stari Jankovci (ST)	0.0378	-0.0178	-0.0694	-0.0136	0.0068	0.0562

Table 17. Female **R** matrix.

	Danilo (DA)	**Dubravice (DB)**	**Nova Raća (NR)**	**Privlaka (PV)**	**Radasinovac/ Korlat (RD/KR)**	**Stari Jankovci (ST)**
Danilo (DA)	0.1402	-0.0686	-0.1547	0.0770	-0.0251	0.0311
Dubravice (DB)	-0.0686	0.1897	0.0491	-0.0866	0.0118	-0.0954
Nova Raća (NR)	-0.1547	0.0491	0.2563	-0.0892	-0.0571	-0.0044
Privlaka (PV)	0.0770	-0.0866	-0.0892	0.1656	0.0166	-0.0834
Radasinovac/Korlat (RD/KR)	-0.0251	0.0118	-0.0571	0.0166	0.1406	-0.0869
Stari Jankovci (ST)	0.0311	-0.0954	-0.0044	-0.0834	-0.0869	0.2390

Table 18. Minimum F_{st} estimates.

Sex	**F_{st}**
Male	0.1121
Female	0.1886

CHAPTER 5

Discussion and Conclusions

The goal of this study was to investigate craniometric variation in a series of medieval Croatian skeletons to test the hypothesis that coastal and continental populations would be morphometrically distinct. M. Šlaus (1998, 2000b) found that coastal and continental medieval Croatian populations could be differentiated by principal components and discriminant function analysis of site means for eight male cranial measurements. Šlaus used these findings to hypothesize a possible route taken by the first Croat settlers of the region. This analysis did not examine the question of "Croat ethnogenesis," as Šlaus (1998) termed it; rather it focused solely on assessing the craniometric variation in medieval Croatian populations.

In addition to Šlaus, the history of the region suggests that coastal and continental groups may be distinct. The region currently defined as Croatia has experienced multiple migrations and invasions from a variety of peoples prior to, during, and since medieval times. The coastal and continental regions, separated by the Dinaric mountain ranges, were subject to intrusions from different areas. The primary migrants along the coast were that of the Roman and Frankish Empires from across the Adriatic, followed by the Slavs, Avars, and Serbo-Croats. In contrast, while the continental region was also affected by Roman, Frankish, Slav, Avar, and Serbo-Croatian invasions, other peoples including Ostrogoths, Magyars, Germans, and Jewish peoples from east of the Danube occupied the area in greater numbers than on the coast (Fine 1983). Such population movements undoubtedly had an effect on the genetic, ethnic, and cultural composition of the two regions. Were the differences, however, great enough to create significant morphological variation?

Craniometric data from three coastal and three continental medieval Croatian sites were used to assess the variation present in medieval Croatian population. The small number of individuals per site and missing cranial measurements required the use of site means in place of raw measurement data. Both male and female means were calculated for each site and the analysis was completed separately for each sex. Canonical variates analysis of site means and the subsequent plotting of canonical scores showed no distinct separation of coastal and continental groups for either males or females. The male data did reveal a distinction between the late medieval site of Nova Raća (NR) and the other earlier medieval Croatian sites.

The separation of Berg (BER) and Nova Raća (NR) from the other groups, as well as the association of the two groups, is understandable when the history and temporal placement of Nova Raća is considered. As noted by Howells (1989), the Berg sample is a mid-eighteenth and ninteenth century central Europe population. Nova Raća, dating from 1300 to 1700 AD, is the most recent sample used in the study and dates after an important event in continental Croatian history. In the twelfth century, Hungary annexed Croatia and encouraged settlement in continental Croatia. Subsequently, continental town populations became more ethnically diverse and included Hungarians, Germans, Jews, and others (Fine 1987). These migrations would have affected the Nova Raća population and resulted in a fourteenth to eighteenth century population that is more morphometrically similar to other central European populations and the Berg than to the earlier continental or coastal Croatian populations.

Matrix comparisons also revealed that there was no significant correlation between biological, geographical, or temporal distances indicating the biological distances between the groups are not significantly related to geographical or temporal distances between the groups. Matrix comparisons using a binary geographic distance matrix, where distance between two coastal and/or two continental sites was zero (0) and distance between coastal and continental sites was one (1), also revealed no significant correlation between biological, geographical, and temoporal distances at the 0.05 level. The correlation between male biological and binary geographical distances while controlling for time had a P value of 0.057, which is almost significant at the 0.05 level, indicating that of all the distance relationships this is likely the most significant.

However, minimum F_{st} for males and females, estimated from derived **R** matrices, are fairly high (0.1121 and 0.1886 respectively) indicating genetic heterozygosity (differentiation) between the groups. The F_{st} estimates are minimum F_{st}, assuming a heritability of 1, if an average heritability were used to calculate F_{st} the values would be higher, indicating greater heterozygosity.

The lack of distinction between the coastal and continental groups based on canonical variates analyses, and the lack of significant correlation between biological, geographical, and temporal distances suggests that the medieval Croatian populations studied were not morphometrically dissimilar. However, estimated minimum F_{st} values for both males and females indicate genetic differentiation between the groups. Thus, while there was no distinct patterning between coastal and continental groups, the groups do exhibit fairly high heterozygosity. Subsequently, it can be argued that the genetic, ethnic, and cultural differences resulting from the various historical population movements in the coastal and continental regions were not great enough to result in distinct morphometric patterning between the early medieval coastal and continental populations, but were great enough to differentiate the Croatian groups studied.

The results of this analysis appear to contradict the findings of Šlaus (1998), which indicated a morphometric distinction between coastal and continental populations. Šlaus used principal components and discriminant function analysis on site means of eight measurements to assess craniometric variation. Possible reasons for the contradiction of results center around the nature of the data sets and the methods used. First, while some of the same site data and cranial measurements were used by both studies, the inclusion of different sites and cranial measurements in this study may partially explain the varying results. Šlaus (1998) also used site means, but it does not appear that sample size was considered in his studies. While Šlaus did not publish sample sizes, he uses the sites of Danilo, Stari Jankovci, and Privlaka, which are known to have small sample sizes (Table 1). Additionally, Šlaus used principal component and discriminant function analyses to differentiate and classify the groups studied. This study did not include discriminant function analysis because means were used rather than raw measurements.

While this study indicated little to no biological distance patterning, the groups were shown to be differentiated based on minimum F_{st} estimates. The significance of the results is lessened by the small sample sizes. Due to considerably low numbers of individuals from each site and missing measurement data, the analysis used mean data and a limited number of variables. While the use of means is not uncommon, nor inappropriate, the small number of individuals contributing to the means greatly affects the scope and strength of this analysis. Clearly, many more individuals, sites, and measurements are required for the analysis to be statistically sound and to make any definitive statements on craniometric variation among medieval Croatian populations.

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