Potential Contributions of Korean Pleistocene Hominin Fossils to Palaeoanthropology: A View from Ryonggok Cave

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INTRODUCTION

> It also seems likely that many questions concerning the origins of the peoples of eastern Asia, Australasia, the Americas and even Europe will only be fully answerable when *Asia* yields up a later Pleistocene record to compare with that already recovered from Europe and beginning to be recovered from parts of Africa.
>
> —Stringer 2002 : 576; emphasis added

As Chris Stringer (quoted above) and others have justifiably noted over the past decade or so, reaching a general consensus on the modern human origins debate has often been hindered by the irregularity of new data coming out of eastern Asia (Bae 2010; Norton and Jin 2009; Shen et al. 2013; Trinkaus 2005). In particular, detailed reports of hominin fossils from the region are often sporadic and published in regional journals, sometimes in the native language of the country of origin (e.g., a fossil found in Korea only published in the Korean language). Furthermore, sometimes these fossils are published only in the gray literature, such as regional conference proceedings that are not disseminated beyond the conference participants. Unfortunately, this situation, more often than not, results in very fuzzy pictures of regional hominin fossil records and what they say. This is the primary problem facing palaeoanthropologists when they attempt to understand the role eastern Asia plays in various scientific debates (Bae 2010; Norton and Jin 2009). For instance, does the eastern Asian hominin fossil record support or weaken any of the major hypotheses (i.e., Replacement, Multiregionalism, Assimilation) that have been proposed to explain the origin of modern humans worldwide?

The vast majority of analyses of late Pleistocene eastern Asian hominin fossils have focused on the three human crania from the famous Zhoukoudian Upper Cave site (Cunningham and Jantz 2003; Cunningham and Wescott 2002; Harvati 2009;

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Kamminga and Wright 1988; Weidenreich 1939*a*, 1939*b*; Wolpoff 1995; Wolpoff et al. 1984; Wright 1992, 1995; Wu 1961). Other studies have concentrated on, or have at least included in their analyses, fossils from China (examples including from Tianyuandong [Shang et al. 2007; Shang and Trinkaus 2010], Liujiang [Liu et al. 2006], Huanglongdong [Liu, Jin, et al. 2010], and Lunadong [Bae et al. 2014]), Japan (Yamashita-cho [Fujita et al. 2007; Suzuki 1983; Trinkaus and Ruff 1996] and Minatogawa [Baba et al. 1998; Kaifu et al. 2011; Suzuki and Hanihara 1982]), Malaysia (Niah Cave [Brothwell 1960]), and recently Laos (Tam Pa Ling [Demeter et al. 2012]). Transitional hominin fossils have also been reported from sites such as Zhirendong in Chongzuo (southern China) (Liu, Wu, et al. 2010). These eastern Asian Pleistocene fossils are contributing to a growing number of regional reviews (e.g., Bae 2010; Etler 1996; Pope 1992). However, questions do exist about some of these sites and materials. For instance, a well-known fact is that the stratigraphic context of the Liujiang cranium is unclear, which calls into question any of the absolute dates that exist for those particular fossils (Bae 2010; Liu et al. 2006; Norton and Jin 2009; Shen et al. 2002). Finding hominin fossils in clear stratigraphic context with solid relative and absolute dates is critical to developing a better understanding of eastern Asian prehistory (Bae 2010).

Although the late Pleistocene hominin fossil records of China and Japan are relatively well known (Kaifu and Fujita 2012; Kaifu and Mizoguchi 2011; Wu 2004; Wu and Poirier 1995), the record of the Korean Peninsula is poorly understood outside of Korea (Bae 2010, 2015; Norton 2000; S.-J. Park 1992). Because the peopling of the Japanese archipelago was likely by some type of watercraft (Norton and Jin 2009; Norton, Kondo, et al. 2010), the Korean Peninsula is the easternmost part of the Eurasian landmass that was reached by terrestrially restricted hominins through the middle of the late Pleistocene. Furthermore, the Korean Peninsula was never cut off from the Chinese mainland as the Japanese archipelago was during almost all periods except extreme glaciations (i.e., MIS 16, MIS 12, and maybe MIS 6 and MIS 2) (Norton and Jin 2009; Norton, Kondo, et al. 2010). Thus, it is quite possible that hominins (presumably *H. erectus*) who reached China sometime during the early and/or middle Pleistocene could have reached the Korean Peninsula as well.

Currently, the earliest potential hominin occupation on the Korean Peninsula is Geumeunmoru (also spelled Kommunmoru). Located outside of Pyongyang, it is penecontemporaneous with Zhoukoudian Locality 13 (early Pleistocene) and Locality 1 (middle Pleistocene) (Bae 2014) (Fig. 1). Roughly 50 percent of the vertebrate taxa identified at Geumeunmoru represent extinct species. However, questions have been raised about the fractured stones and whether they are indeed the product of purposeful manipulation by hominins or are simply geofacts. The next oldest hominin occupations on the peninsula may be some of the sites in the Imjin-Hantan River Basins (henceforth IHRB), north of Seoul, that may date as early as 350,000 years old (Bae et al. 2012; Norton et al. 2006; Norton and Bae 2009). However, the IHRB sites are open-air sites that only produce stone artifacts. Because of the high degree of soil acidity in the peninsula, bone preservation at open-air sites (except coastal shell middens) is very poor (Norton 2000).

Bone preservation is much better in the limestone mountainous regions of the peninsula. Fieldwork in these areas has revealed extensive cave systems, some of which

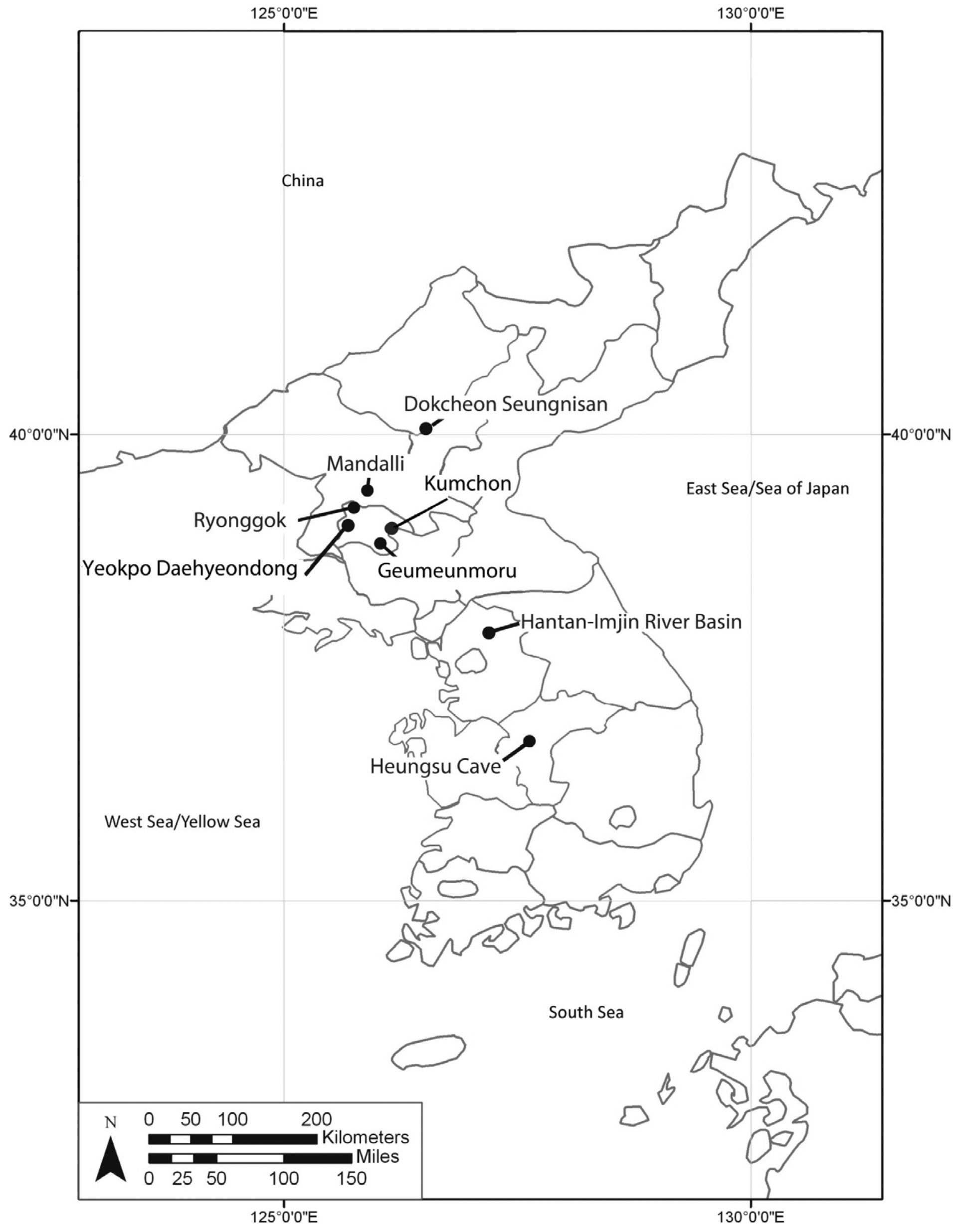

Fig. 1. Map of Korean Peninsula with sites mentioned in text. Note that most of the important hominin fossil localities are located in the Democratic People's Republic of Korea.

have produced hominin fossils. We necessarily focus our discussion on the materials excavated from these caves in order to understand which hominin taxa occupied which area during which time period (Bae 2014). Currently, Pleistocene hominin fossils have been reported from eight separate cave sites (Chung 1996; Norton 2000;

S.-J. Park 1992). A ninth cave site (Heungsu Cave) contained the remains of a burial of a human child that was originally thought to date to c. 40,000 years ago (Lee et al. 1991; Park and Lee 1990). However, as discussed below, the Heungsu child now appears to date to a more recent time period (de Lumley et al. 2011; Norton and Jin 2009).

Yeokpo Daehyeondong and Dokcheon Seungnisan currently have the oldest hominin fossils on the peninsula; both sites date to the middle–late Pleistocene transition, based on associated faunas (ARL 1990; Bae 2010, 2014; Kim et al. 1990; Norton 2000). The taxonomic assignments of these hominin fossils are unclear, so for now it might be safest to assign them to mid-Pleistocene *Homo*.[1] The Mandalli cave site has an assortment of modern *H. sapiens* fossils, including partial calvarium, mandible, femur, humerus, and innominate, found in association with clear Late Palaeolithic stone and bone tools (Bae 2014; Norton 2000). The Late Palaeolithic artifacts include microblades and a microblade core produced on obsidian.[2] As noted by Bae (2014), bone tools at Mandalli need to be further evaluated. Given the site's age and proximity to better-known Late Palaeolithic sites such as Zhoukoudian Upper Cave and Xiaogushan, where a diversity of osseous implements have been identified (Norton and Gao 2008; Norton and Jin 2009), the presence of bone tools at Mandalli would not be surprising. Several modern *H. sapiens* fossils were identified in South Korea at sites such as Gunanggul, Jeommal Cave, and Sangsi Rockshelter (Norton 2000; S.-J. Park 1992). Unfortunately, these specimens have not been studied in any great detail.

To better understand the contributions the Korean Pleistocene hominin fossils offer to various palaeoanthropological debates, here we present a morphometric analysis of two relatively complete hominin crania from Ryonggok, a late Pleistocene cave site located just outside Pyongyang, the present-day capital of the Democratic People's Republic of Korea. The purpose of this study will be to assess the most parsimonious taxonomic association of the Ryonggok hominin fossils. Because of the difficulty of accessing Korean data, in Appendix A and Appendix B we present as much raw metric cranial and mandibular data as we could track down for the important North Korean hominin fossils from Ryonggok, Mandalli, Geumchun, and Seungnisan (see also Bae 2010).

BACKGROUND

In the 1970s and early 1980s, a series of palaeoanthropological field surveys were conducted in the Pyongyang region. One of these surveys led to the discovery of Ryonggok Cave in 1980 (Jun et al. 1990; Y.-C. Park 1992; Sohn 1990). Ryonggok is actually comprised of two caves (#1 and #2), but despite the identification of eight stratigraphic layers, only fifteen lithic artifacts and no vertebrate fossils were reported from Ryonggok #2 (Sohn 1990). This article therefore focuses only on the findings from Ryonggok #1.

Ryonggok was excavated twice between 1980 and 1981 (Jun et al. 1990). More than 20 m of deposits were discovered, with 13 stratigraphic layers identified: Layer 13 represents the topsoil and Layer 1 represents bedrock. Archaeological materials and hominin fossils were found in layers 12–8, with cultural deposits between 6–7 m in thickness. Layer 12 (cultural layer 5) contained Neolithic artifacts (e.g., Chulmun potsherds), while the other four cultural layers, 11–8, had Palaeolithic artifacts and Pleistocene vertebrate faunal materials (Bae 2014; Jun et al. 1986; Y.-C. Park 1992; Sohn 1990).

A mixture of Palaearctic taxa (e.g., *Equus* sp., *Capreolus capreolus*) and Oriental taxa (e.g., *Bubalus* sp.) were identified in the faunal assemblage (Sohn 1990). Given the fact that the Palaearctic/Oriental biogeographic zone boundary moved north and south during interstadial and stadial periods (Norton, Jin, et al. 2010) and the relative thickness of the deposits, the presence of mixed fauna in Ryonggok is not all that surprising. Presence of extinct taxa (e.g., *Dicerorhinus* cf. *mercki*, *Hyaena* sp.) clearly indicates that the deposits below Layer 12 date to the Pleistocene (Sohn 1990). A series of absolute dates have been reported from the cave (Y.-C. Park 1992; Sohn 1990). A thermoluminescence (TL) date was initially reported from layers 8 and 9, placing the deposits between 500,000 and 400,000 years old. Two separate uranium-series dates from Layer 8 (cultural layer 1) resulted in much more recent ages (110,000, 71,000). A third U-series date from Layer 9 (cultural layer 2) placed the deposits between 49,000 and 46,000 years old. The younger U-series dates are more generally accepted than the TL age (Bae 2014; Norton 2000; Y.-C. Park 1992).

The lithic artifacts from Ryonggok are typical of eastern Asian Early Palaeolithic core and flake tools (Gao and Norton 2002). Although tools such as blades and tanged points that typically signal the advent of the Late Palaeolithic in the region are absent (Bae and Bae 2012; Pei et al. 2012), this should not be considered unusual. Blade and tanged point technology did not simply sweep into the region with the arrival of modern humans (Bae and Bae 2012). In many regions of eastern Asia we see a continuation of traditional Early Palaeolithic core and flake tools well after blades and tanged points appeared. It is not until after c. 30,000–25,000 years ago that blades, tanged points, and microblades begin to dominate the lithic toolkits in Northeast Asia (Bae and Bae 2012; Pei et al. 2012; Seong 2009). Blades have yet to be concretely identified in Southeast Asian Pleistocene contexts (Norton and Jin 2009; Qu et al. 2013). Thus, we should be careful to directly associate a specific hominin taxon with a specific lithic tool industry, at least in eastern Asia.[3] This is particularly relevant to the eastern Asian Palaeolithic record because there is little or no evidence attesting to these technologies having appeared suddenly or rapidly replaced older technologies.

A total of 30 hominin fossils were found *in situ* between layers 8 and 12, representing at least five separate individuals (Bae 2010; Jun et al. 1990; Norton 2000; Y.-C. Park 1992; Sohn 1990). The Ryonggok hominin fossil assemblage is comprised of at least five partial mandibles, one partial maxilla, at least three humerus and three femur fragments, assorted vertebra specimens, and three innominate fragments. Bae (2010) suggests that, given the advanced biological ages of the mandibles (based on tooth eruption and wear), Ryonggok may actually represent a Late Palaeolithic burial site. Although little other evidence has been presented to support the burial argument, it should be noted that a wide diversity of pollen taxa were identified in the deposits (Bae 2014; Sohn 1990), which is reminiscent of the Shanidar Cave Neanderthal burial (Solecki 1971). Future multidisciplinary study of the site and associated materials should be designed to test this hypothesis.

More importantly for the purposes of this article, however, were the recovery of two relatively intact crania (#7 from Layer 9 and #3 from Layer 10). These two crania form the core of the following morphometric analyses.

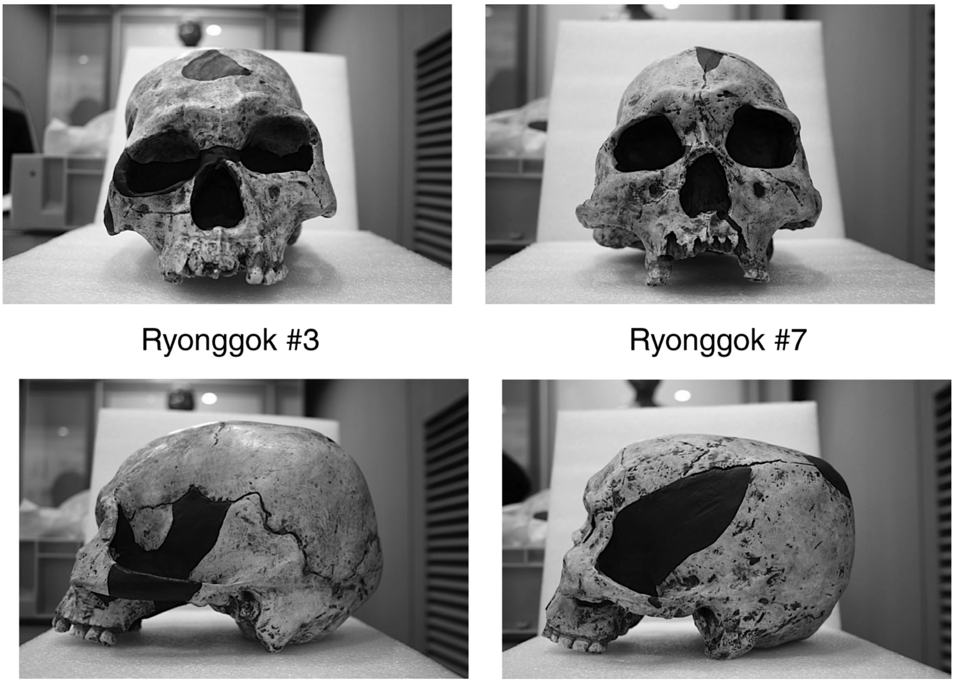

Fig. 2. Frontal and lateral views of the casts of Ryonggok #3 and #7 crania stored in the Chungbuk University Museum, Republic of Korea (not to scale). (Photographs by author)

MATERIALS AND METHODS

Among the hominin fossils recovered during the excavations at Ryonggok, two relatively intact skulls were found (Fig. 2). The following descriptions of Ryonggok #3 and Ryonggok #7 are from Jun and colleagues (1990). Due to access constraints, it was impossible for us to directly observe the original fossils, but we present below the linear metric data originally published by North Korean scientists in this article. We were able to examine casts of these important fossils curated at the Chungbuk National University Museum in Cheongju, Republic of Korea. These casts of the Ryonggok hominin crania were produced by French researchers; they made the casts from casts Chinese palaeoanthropologists had received from North Korean scientists more than two decades ago (Sunjoo Park, pers. comm.). We acknowledge problems with conducting analyses of casts, especially casts of casts (McNulty and Smith 2009). However, since it is currently impossible to obtain access to the original Ryonggok hominin fossils that are curated in the DPRK, we feel any analysis is better than no analysis.

Ryonggok #3

Ryonggok #3 is relatively intact and well preserved, including frontal, parietal, occipital, temporal, and facial bones (Jun et al. 1990). After refitting all of the pieces of the skull, it appears to have suffered at least some degree of postdepositional deformation, possibly from sediment or rockfall compaction. As a result of this deformation, the parietals, occipital, and temporal bones do not fit perfectly anatomically. The authors of the original publication admit that because of this deformation, the linear measurements for this particular skull are overestimates (Jun et al. 1990). They note that, despite its large cranial capacity (approximately 1650 cm^3) and high skull height (characteristic of modern humans), #3 retains a variety of ancestral traits. For instance, it is thought the skull retains a sagittal eminence, has high superciliary arches, and a narrow frontal-head breadth index, all traits reminiscent of more archaic hominins.

Ryonggok #7

Ryonggok #7 was found in about 100 fragments in the same proximate area (Jun et al. 1990). Because most of the fossils were in good condition, it was possible to refit most of them to form a nearly complete skull. The frontal bone is almost perfect, but the parietal bones were fractured in the posterior to central areas. The right temporal bone was attached to the occipital bone. The mastoid process from the right temporal bone is gone. The left temporal bone was fairly intact, including a perfectly intact mastoid process. The base of the skull could not be reconstructed from the fragments. Although #3 clearly suffered from some degree of postdepositional deformation, #7 appears to have been better preserved despite its fragmentation; the linear measurements are considered to be close to original. Modern human traits cited for #7 include a large cranial capacity (approximately 1450 cm^3) and a relatively high skull (130 mm). As with #3, #7 appears to retain some ancestral traits, including a sagittal eminence and a more posteriorly situated bregma (Jun et al. 1990).

In addition, using linear metric teeth data compiled by Bae (2010 : 80, Table 2), we plotted the Ryonggok hominin fossil tooth data against various modern human and hominin fossils, including creating convex hulls for each individual distribution (see Appendix C).[4]

Comparative Materials

The comparative data for the teeth linear measurement (mesial-distal, buccal-lingual) analyses were culled from published sources (Bae 2010; Bailey and Liu 2010; Kaifu et al. 2005; Kimbel et al. 2004; Liu, Wu, et al. 2010; Macaluso 2010; Robinson 1956; Tobias 1967; Voisin et al. 2012; Wood 1991; Wu and Poirier 1995). In order to be consistent with other studies (i.e., Bae et al. 2014; Xiao et al. 2014), and since we are palaeontologists rather than dentists, we labeled maxillary teeth in the uppercase (i.e., M1, M2, M3) and mandibular molars in the lowercase (i.e., m1, m2, m3).[5] We present tabulated data for the six molars (three upper, three lower) in Appendix C.

We collected comparable cranial morphometric data on a series of recent modern human and Upper/Late Palaeolithic modern humans (Table 1). The modern human category is divided into two separate groups: modern Koreans dating to the Chosun dynasty (A.D. 1395–1897) stored in Hanyang University Museum and Chungbuk National University Museum in the Republic of Korea; and modern Chinese,

Table 1. Specimens used in this Study (N = 132)

GENUS/SPECIES	SPECIMENS
Modern humans (N = 113)	Chinese (N = 9); Korean (N = 79); Nigerian (N = 25)
Upper Palaeolithic modern humans (N = 17)	Brun 3; Cro Magnon 1; Fish Hoek 1; Furfooz 1; Gambles Cave 4; Jebel Irhoud; Liujiang; Mladec 1; Oberkassel 1; Predmost 3, 4; Scaligneaux 2; Shanidar 1; Skuhl 5; ZKD UC 101, 102, 103
Ryonggok (N = 2)	Ryonggok 3, 7

Japanese, and Nigerians stored in the American Museum of Natural History (AMNH). The Upper/Late Palaeolithic modern human fossils are casts stored in Chungbuk National University Museum or AMNH.

Data Collection

For a comprehensive assessment of the cranial shape of the Ryonggok subjects, Euclidean coordinates data (Table 2) were collected using microscribe digitizers. Such data allows for the analysis of three-dimensional (3D) shape and size variations, as well as for the extraction of two-dimensional (2D) linear variables (Table 3), and is less prone to inter-observer uncertainty (Franklin et al. 2005). Linear measurement data culled from Jun and colleagues (1990) were also used to compare the 2D variables extracted from the 3D coordinates. Measures that were different by up to 5 mm were excluded (i.e., corresponding landmarks were excluded from geometric morphometric analyses). Because of the evident Ryonggok fossil cast distortion, the facial data were preferred and only symmetric components were taken into account for geometric morphometrics (asymmetry being primarily taphonomic).

Table 2. Landmark Definitions (Numbers Correspond to Points Shown in Figure 11)

LEFT	RIGHT	LANDMARK	DEFINITION
1		Nasion	Midline point on the nasofrontal suture
2		Nasospinal	Midline point on the inferior border of the piriform aperture at the intermaxillary suture
3	7	Alare	Most lateral point of the piriform aperture
4	8	Dacryon	Junction of the sutures between the frontal, maxillary, and lacrimal bones
5	9	Frontomalare Orbitale	Point on the orbital rim at the junction of the sutures between the frontal and zygomatic bones
6	10	Zygoorbitale	Point of the zygomaxillary suture on the orbital rim
N/A	N/A	Supraconchion	Highest point on the orbital rim
N/A	N/A	Infraorbitale	Lowest point on the orbital rim
N/A	N/A	Ectoconchion	Most lateral point of the orbital rim following a line bisecting the orbit from the dacryon
N/A	N/A	Frontotemporale	Most antero-medial point of the linea temporalis superior

TABLE 3. LINEAR VARIABLES USED IN THIS STUDY AND CORRESPONDING LANDMARKS

LINEAR VARIABLE	CORRESPONDING LANDMARKS
Frontal breadth	Frontotemporale right and left
Nasal breadth	Alare right and left
Nasal height	Nasion and nasospinale
Orbital height	Supraconchion left and infraorbital left
Orbital breadth	Dacryon left and ectoconchion left

Analyses

Probabilistic distances between each Ryonggok cranium and the comparative populations (Upper Palaeolithic, Korean, and Modern) were computed using adjusted Z-scores including a student law following Maureille and colleagues (2001). This approach allows for the simple quantification of the proximity of a specific subject compared to a subsample. The lower the score, the closer the individual is to the target population (for application, see Crevecoeur et al. 2010; Scolan et al. 2012).

Prior to the analyses, interobserver measurement variations were controlled and minimized in the 3D data collected by two observers (Christopher J. Bae and Claudia Astorino). The retained landmarks are types I and II (Bookstein 1991); all type III and several type II were excluded to ensure data comparability and integrity of the results. After cleaning the data, it was decided to focus 3D analysis on the upper facial region since it provided a sufficient number of reliable homologous landmarks among the available specimens. The 3D coordinates of the ten landmarks were standardized with a Procrustes superimposition; a canonical variate analysis (CVA) was performed on the residuals between the different groups with MorphoJ software (v. 1.06b) (Klingenberg 2010). The CVA was run with a permutation test (10,000 iterations) on the symmetric shape component. A regression of size (centroid size) on shape (symmetric component) was also used to detect potential static allometry in the facial region of the subjects.

RESULTS

Teeth

Amongst the teeth plotted, we found a general separation between older hominins (e.g., australopiths, *Paranthropus*, Early *Homo*) and more recent modern human groups (e.g., Upper Palaeolithic, Mesolithic, Neolithic modern humans). *Homo erectus* and Neanderthals generally fall in between these two larger groupings, with the former being larger and the latter displaying more overlap with Middle and Upper Palaeolithic modern humans. Given that at least some of the North Korean specimens are representative of Upper/Late Palaeolithic modern humans (e.g., Mandalli, Kumchon), it is perhaps not surprising that most of the North Korean fossils fall outside the range of larger, older hominins (e.g., *H. erectus*, Early *Homo*, australopiths) (Figs. 3–8). In fact, the teeth from Ryonggok #3 (one of the primary foci of this article) clearly falls within the range of more recent modern humans (Upper Palaeolithic, Mesolithic, Neolithic) and well outside the range of Neanderthals and *H. erectus* (Figs. 3–5). The North Korean hominin mandibular teeth display a greater range of variation, with the

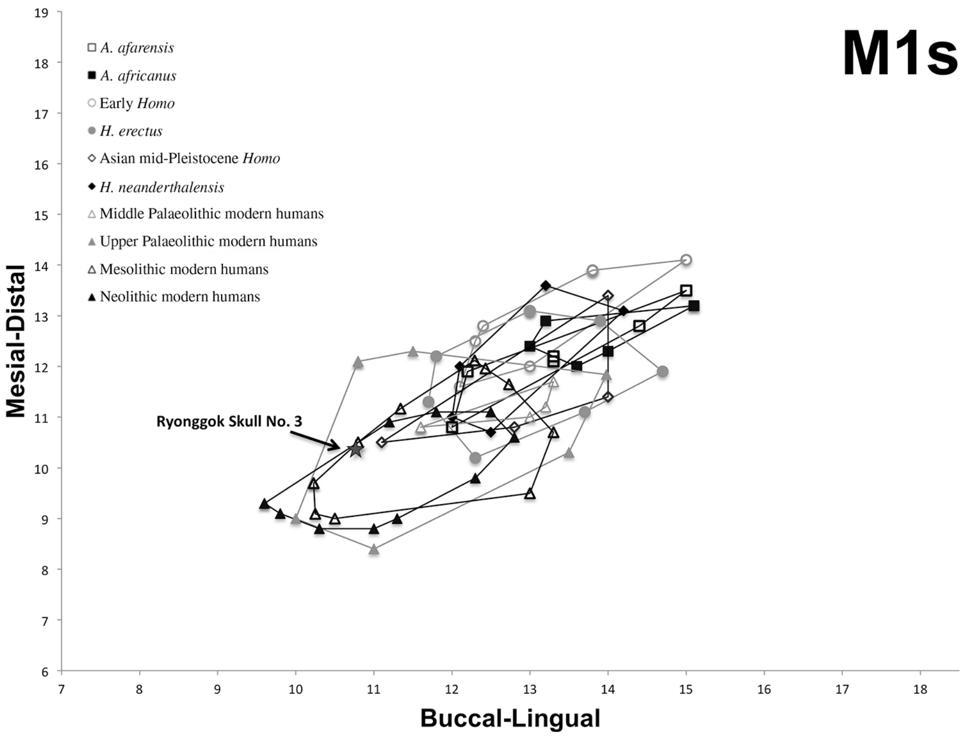

Fig. 3. Buccal-lingual/mesial-distal linear metric plot of the M1s.

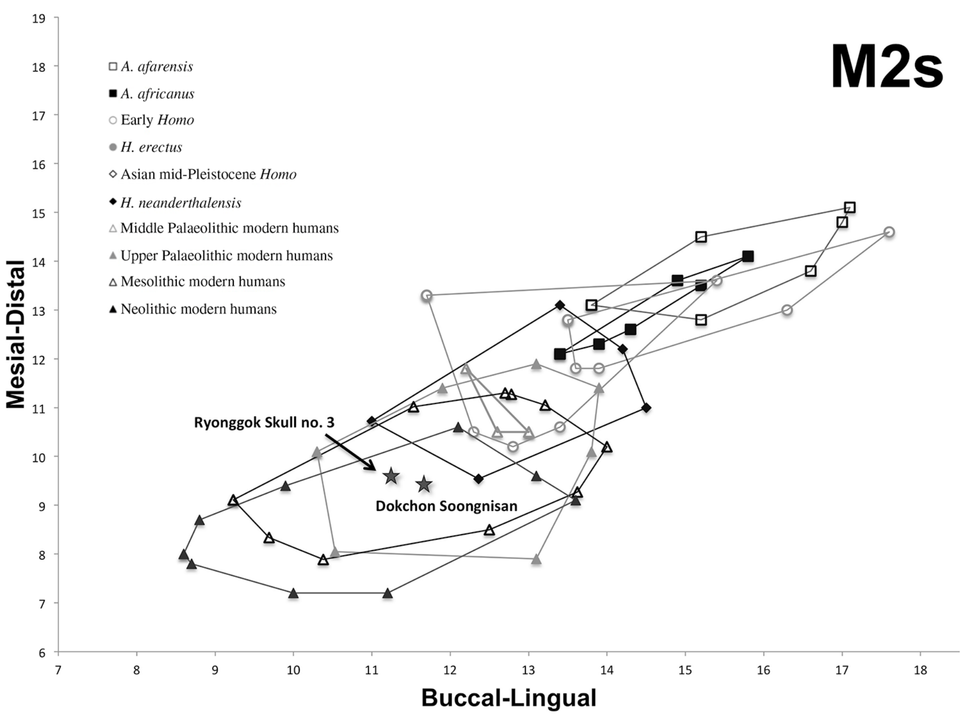

Fig. 4. Buccal-lingual/mesial-distal linear metric plot of the M2s.

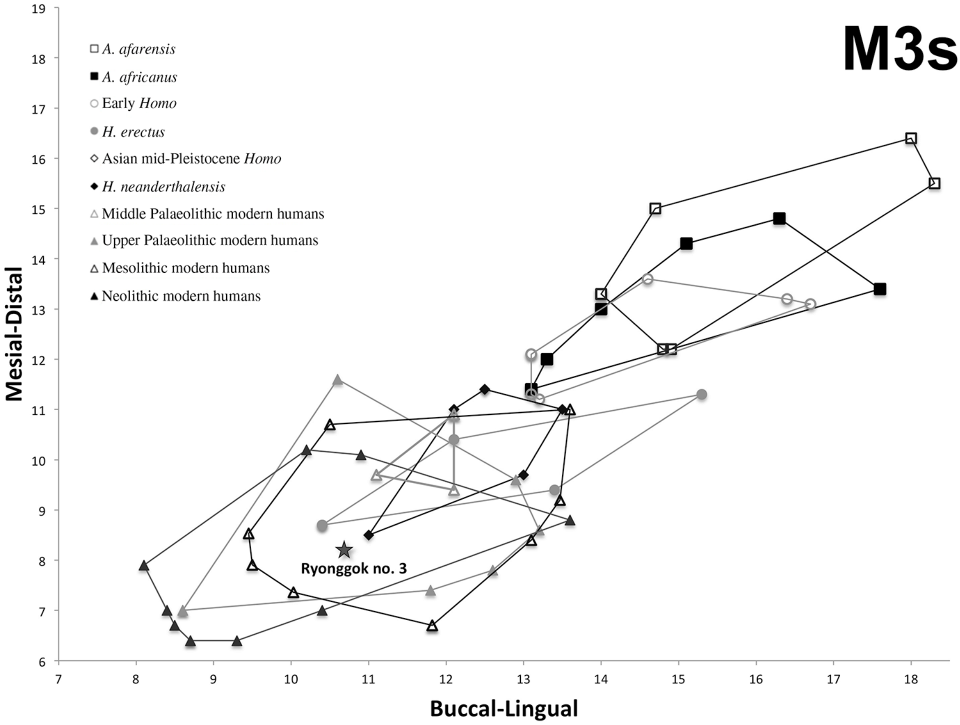

Fig. 5. Buccal-lingual/mesial-distal linear metric plot of the M3s.

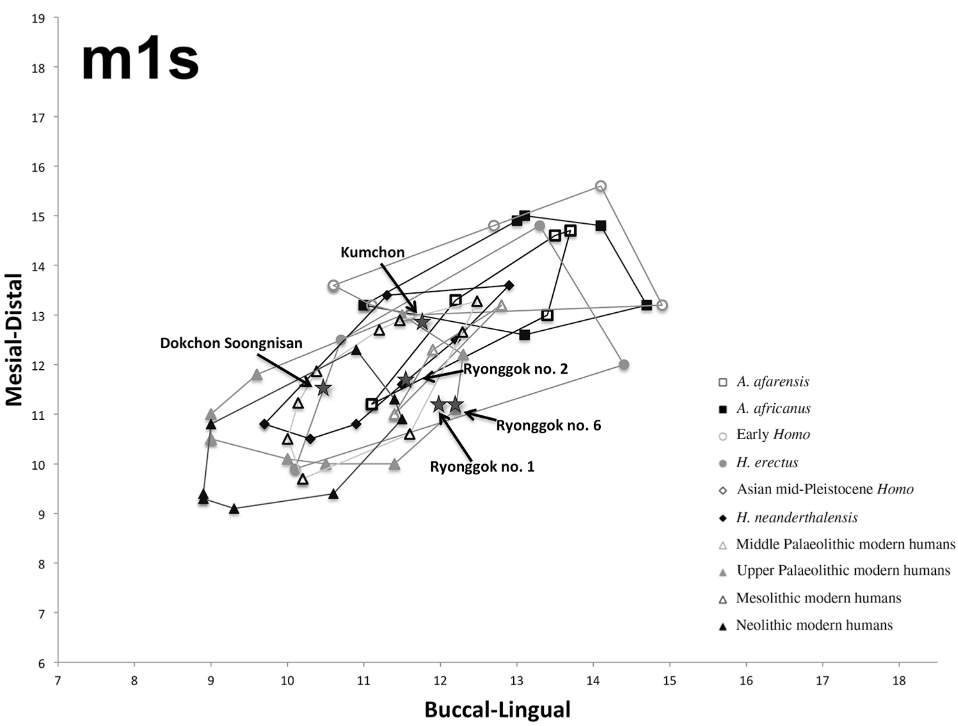

Fig. 6. Buccal-lingual/mesial-distal linear metric plot of the m1s.

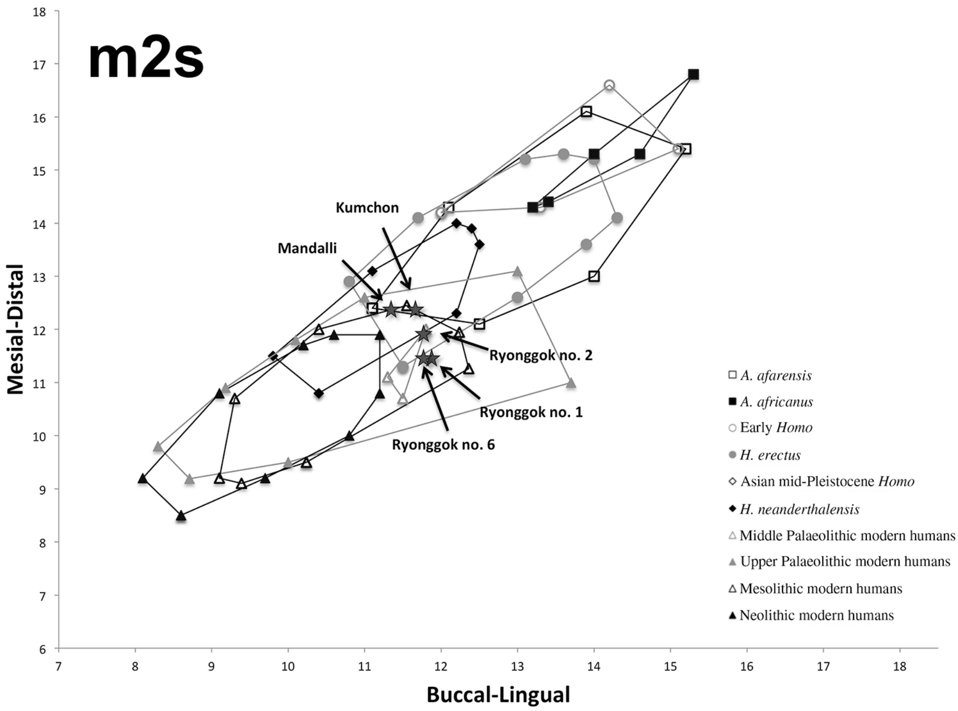

Fig. 7. Buccal-lingual/mesial-distal linear metric plot of the m2s.

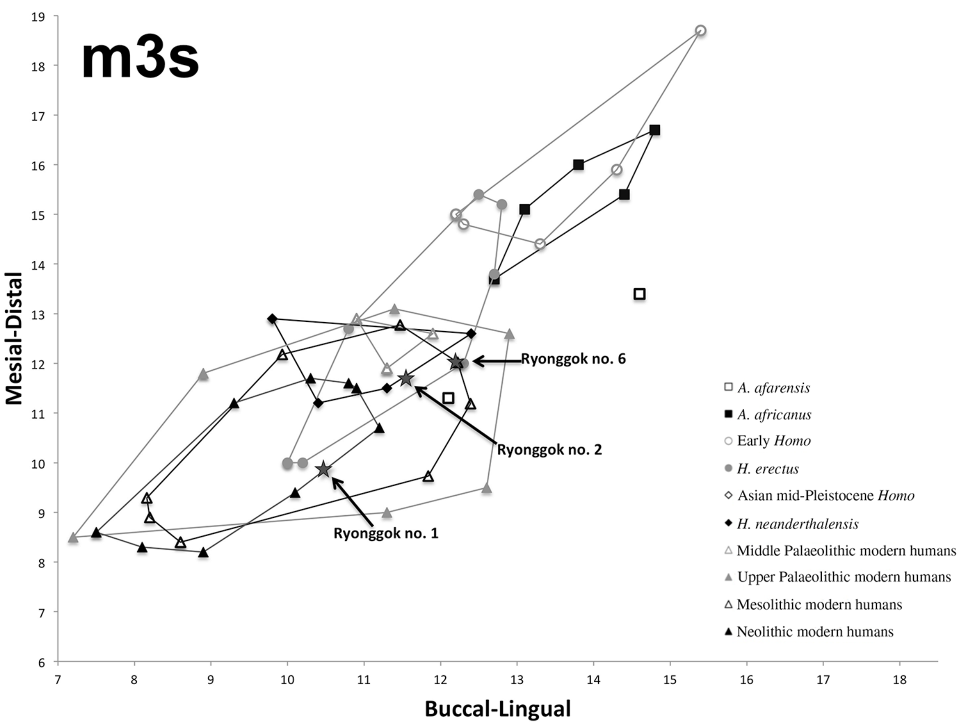

Fig. 8. Buccal-lingual/mesial-distal linear metric plot of the m3s.

Ryonggok teeth overlapping fairly extensively with the Neanderthals and *H. erectus* (Figs. 6–8). The Mandalli and Kumchon mandibular teeth, representative of Upper/Late Palaeolithic modern humans, also easily fall within range of these older hominin groups and at the upper range of the more recent modern human groups.

Crania

Table 4 displays the descriptive statistics of the Ryonggok fossils and comparative material.[6] Variations amongst the Ryonggok subjects relative to the three comparative metagroups can be visualized through Z-scores (Figs. 9 and 10). Globally, Ryonggok #3 appears closer to the Upper Palaeolithic group (Fig. 9). It deviates at nasal breadth

Table 4. Descriptive Statistics (in mm) for the Linear Variables (s.d. = Standard Deviation)

VARIABLE	FRONTAL BREADTH	NASAL BREADTH	NASAL HEIGHT	ORBITAL HEIGHT	ORBITAL BREADTH
Ryonggok #3	92.73	27.83	50.97	34.49	40.84
Ryonggok #7	97.91	28.13	53.50	35.63	42.71
Korean	91.45	26.43	51.41	36.75	40.33
mean s.d.	(4.32)	(1.69)	(3.34)	(2.53)	(2.01)
Upper Palaeolithic	99.05	28.22	50.80	33.54	41.66
mean s.d.	(5.37)	(2.65)	(6.00)	(3.19)	(3.70)
Modern	94.36	27.35	49.66	35.36	39.99
mean s.d.	(5.32)	(2.19)	(4.58)	(3.19)	(1.85)

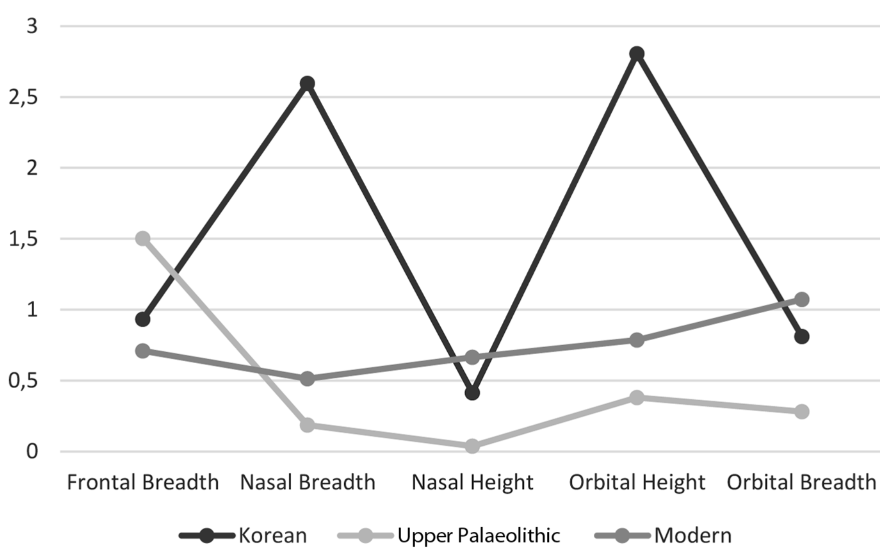

Fig. 9. Adjusted Z-scores for Ryonggok #3.

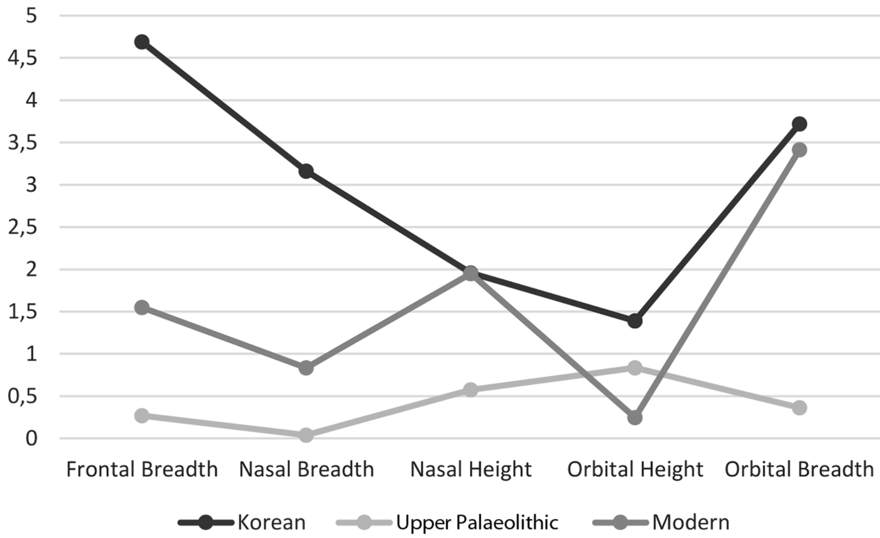

Fig. 10. Adjusted Z-scores for Ryonggok #7.

and orbital height from the Korean individuals. Ryonggok #7 displays dimensions closer to the Upper Palaeolithic group, with important deviations at frontal breadth and orbital breadth (Fig. 10).

Major deviations represented by Z-scores > 2 can be attributed to facial asymmetry and fossil distortion likely due to missing parts of the original fossil and subsequent reconstruction of the cast. Linear analyses are here limited by the nature of the material and lack of independent variables. By virtually correcting the taphonomic distortion and/or proposing a different reconstruction of the skull, metric particularities involving high deviations might be smoothed (Gunz et al. 2009). However, the general trend of the two crania indicates a stronger similarity with Upper Palaeolithic individuals. This relation observed through Z-scores may be triggered by higher standard deviations in the metrics of the latter group. A closer evaluation of the facial shape of the Ryonggok subjects is necessary and can be performed through geometric morphometrics.

The CVA clustered the four groups (Ryonggok, Korean, Upper Palaeolithic, Modern) into three canonical variates, each representing specific homogeneous shape changes. CV1 accounts for 83.7 percent of the variance; CV2 represents 14.3 percent; and CV3, accounting for only 2 percent of the total shape variance, is excluded from the results and interpretation (Fig. 11).

Through the CVA, the groups are optimally separated with homogeneous shape changes at the 10 landmarks. The Ryonggok subjects are relatively centered within the distribution of CV1. A positive value corresponds to the Upper Palaeolithic and Modern subjects, who display a shorter nasal height, a wider nasal roof, and a wider face. Inversely, the Korean group corresponds to a larger nasal height and a smaller interorbital distance. CV2 separates the more recent groups (Korean and Modern) from the Upper Palaeolithic and Ryonggok individuals. The related shape changes

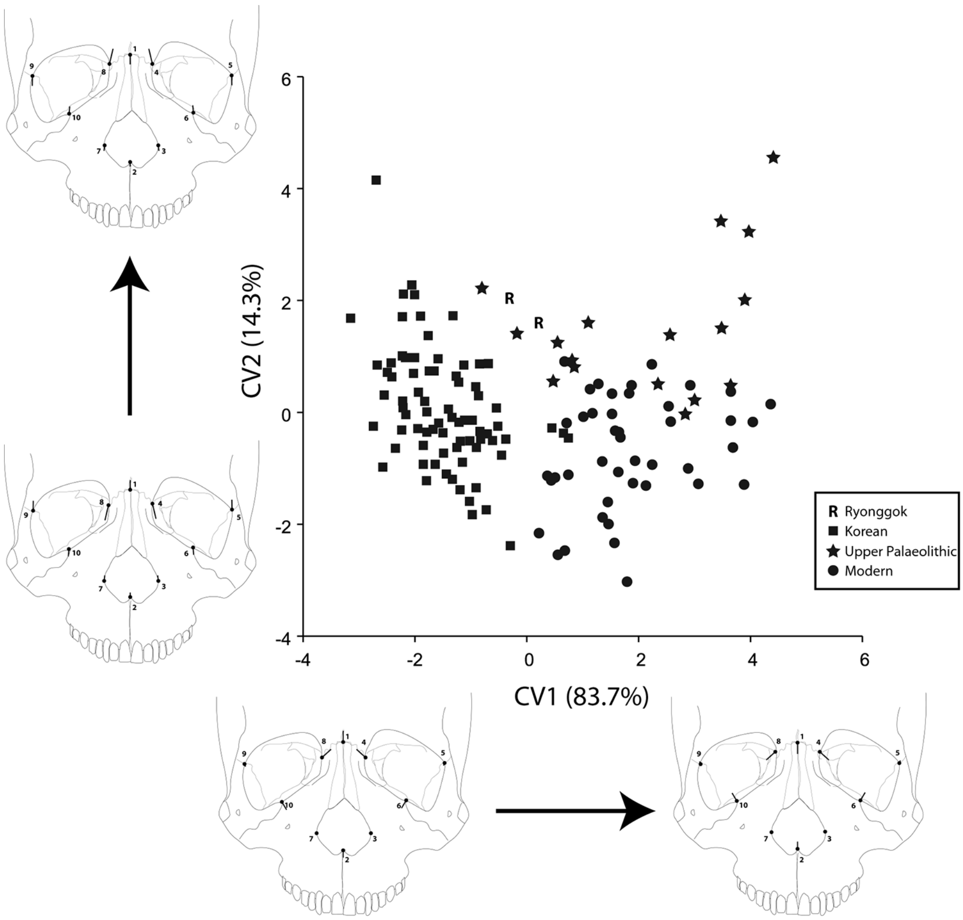

Fig. 11. Distribution of Ryonggok, Korean, Upper Palaeolithic, and Modern individuals following a CVA of a 10-landmarks configuration on the mid-facial region. Shape changes explained by the canonical variates (CV) are displayed for a score of −10 and +10 (dots represent average shape configuration).

are a downward shift of the inferior nasal zone, a flattening of the nasal roof, and a more rectangular orbital region for the latter subjects. These shape changes concern exclusively the symmetric component, any asymmetry having been automatically extracted by MorphoJ. Such results are thus partly free from potential fossil distortion or reconstruction mistakes.

A regression of size on shape revealed a significant slight static allometry (1.8 percent of predicted shape through size, $p = 0.02$), mainly due to the bigger size of some Upper Palaeolithic individuals (mean centroid size, cs = 110.5). Modern individuals and Koreans tend to be smaller (cs = 104.9 and cs = 102.8, respectively), and Ryonggok subjects are slightly bigger than the recent subsample, though still in the range of the three comparative samples (Ryonggok #3 = 105.7; Ryonggok #7 = 111).

In terms of distance (combined through CVs), the Ryonggok subjects are closer to the Upper Palaeolithic group and the Korean individuals. However, after permutation,

Table 5. Mahalanobis Distances among Group (p-Values from Permutation Tests between Parentheses)

VARIABLE	KOREAN	MODERN	UPPER PALAEOLITHIC
Modern	3.3927 ($p < 0.0001$)	—	—
Upper Palaeolithic	3.9333 ($p < 0.0001$)	2.2673 ($p < 0.0001$)	—
Ryonggok	3.1132 ($p = 0.0515$)	3.7357 ($p = 0.0188$)	3.1863 ($p = 0.5789$)

the p level indicates a stronger similarity in facial shape to the Upper Palaeolithic group than to the Korean group (Table 5).

DISCUSSION

Metric analysis of the Ryonggok maxillary teeth suggests closer affiliations with recent modern humans (Upper/Late Palaeolithic, Mesolithic, Neolithic) than with older hominins. The Kumchon and Mandalli teeth also support the Upper/Late Palaeolithic human alignment. However, the Ryonggok mandibular teeth easily fall within the range of the Neanderthal and at the low end of the range of the *H. erectus* teeth. Until a more detailed analysis (e.g., geometric morphometrics) of the various North Korean teeth is conducted, we suggest caution is warranted to prevent overinterpretation of the mandibular teeth; particularly any interpretation based solely on tooth metric dimensions is to be avoided, since these teeth overlap a great deal.

Linear metric and geometric morphometric analyses of Ryonggok skulls #3 and #7 indicate that they more closely align with the Upper Palaeolithic group than with more recent modern humans. Earlier studies have suggested that the Ryonggok hominins, though clearly not of more recent origin (post Pleistocene–Holocene transition), retain modern features, including a generally rounded cranial vault, weak supraorbital tori, inclined forehead, and evidence of a mental eminence on the mandibles (Bae 2010; Jun et al. 1990; Norton 2000). Overall, we are presented with a picture of a mosaic of characters that appear on each of these crania, reminiscent of other late Pleistocene Late Palaeolithic humans in the region (e.g., Zhoukoudian Upper Cave, Tianyuandong).

Despite our reservations about the quality of the casts of the casts, the one general conclusion we draw from this study is that Ryonggok #3 and #7 probably represent a Northeast Asian early Late Palaeolithic foraging group. However, until it is possible to access the original fossils, reassess the reconstruction (Gunz et al. 2009), and conduct in-depth linear metric and geometric morphometric analyses of these important fossils, we reserve opinion as to whether these North Korean late Pleistocene hominin fossils support arguments for a modern human migration into the region replacing indigenous hominin groups or whether some degree of admixture occurred.[7]

The Korean hominin fossil record has much to offer various debates in palaeoanthropology (Bae 2010; Norton 2000). However, the Korean hominin fossils must be evaluated with an objective, critical eye. A good example of this is the Heungsu child burial. The problem with the findings from Heungsu Cave is that, before a multidisciplinary analytical research program had been set up to study the child's bones and the site's context, they were almost immediately presented to the public as representing the "oldest" (purportedly c. 40,000 years old) child burial of its kind in the world (Lee et al. 1991; Park and Lee 1990). Numerous archaeologists (who were not part of the Heungsu Cave excavation) have questioned the purported c. 40,000-year-old date for the child burial due to unclear stratigraphic context, absence of associated artifacts, and necessity for closer evaluation of the child's bones. Given this evidence (or lack thereof), it has long been speculated that the Heungsu burial might be of much more recent origin (Norton and Jin 2009). Indeed, an AMS date taken directly from a bone fragment from the skeleton yielded a much more recent age of A.D. 1630–1893 (de Lumley et al. 2011). Although the Korean research team who found the Heungsu child dismissed the more recent date by arguing that it was most likely due to contamination of the sample, there is little reason not to believe the radiocarbon date, particularly because it is based on a sample taken directly from the skeleton. Thus, before this type of potentially important information is disseminated to the public, it is probably best that a site and associated materials be subjected to thorough scientific scrutiny from multiple angles.

CONCLUSION

The Ryonggok fossils tentatively contribute to a growing record of Late Palaeolithic early modern humans in Northeast Asia (e.g., Zhoukoudian Upper Cave, Tianyuandong). One of the questions that future research should address is whether these Ryonggok foragers were part of a larger dispersal into the region from Northwest Asia following a northerly route or perhaps an earlier migration northward from modern humans initially arriving in Southeast Asia. Yet another possibility is that the Ryonggok humans were the result of some degree of admixture between migrating modern humans and indigenous mid-Pleistocene *Homo* (or even older *H. erectus*). Hopefully, there will be more detailed analyses of the Ryonggok and other Korean hominin fossils. For example, the size and shape relations between the different groups and the Ryonggok subjects could be confirmed and cross-validated with configurations of landmarks covering different cranial regions such as the vault, base, and mandible. Such analyses would contribute more to these current debates in palaeoanthropology.

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Appendix A. Raw Data Provided for Published Korean Crania

북한 용어	ENGLISH TRANSLATION	RYONGGOK #7	RYONGGOK #3	MANDALLI
머리뼈 길이	Cranial length	190 mm	204 mm	201
머리뼈 너비	Cranial breadth	132 mm	142 mm	146
머리뼈 지수	Cephalic index	69.7	69.7	72.6
머리뼈 높이 (귀점에서)	Cranial height (from porion)	130 mm	132.4 mm	123
머리뼈 높이 (G-Op) 에서	Cranial height (from G-Op)			110
머리뼈 높이 지수 (G-Op 에서)	Cranial height index (from G-Op)			56.3
이마작은너비	Minimum frontal breadth		92.2 mm	
이마큰너비	Maximum frontal breadth		114 mm	
이마 곧은길이	Frontal length—straight	118 mm	118.4 mm	115.4
이마 굽은길이	Frontal length—curved	138.2 mm	138.6 mm	140
이마 (굽은) 지수	Frontal curvature index	84.6	89.6	82.4
앞숫구멍점각	Bregma angle	60°60°60°	54°	57°
이마각	Metopion angle	81°	82°	80°
앞숫구멍점(위치)지수	Bregma index	32.6	34.2	33.3
웃머리뼈 곧은길이	Parietal length—straight	115.6 mm	130.2 mm	122
웃머리뼈 굽은길이	Parietal length—curved	134.3 mm	138.6 mm	139
웃머리뼈 지수	Parietal index	86.7	93.8	85.4
옆머리뼈 높이	Temporal height		53.6 mm	
옆머리뼈 길이	Temporal length		92 mm	
옆머리뼈 지수	Temporal index		58.2	
뒤머리뼈 너비	Occipital breadth	115.6 mm	117 mm	107.3
뒤머리-웃머리너비지수	Occipital-parietal breadth index		84.7	
뒤머리뼈각	L-I-N angle			79
뒤머리뼈 곧은길이	Occipital length—straight		103 mm	
뒤머리뼈 굽은길이	Occipital length—curved		127 mm	
겉뒤머리륭기점과 속뒤머리륭기점 사이거리	Distance between external and internal occipital protuberence	21 mm		
큰구멍 길이	Foramen magnum length		46 mm	
큰구멍 너비	Foramen magnum breadth		38.2 mm	
뇌수용적	Cranial capacity	1450 cm^3	1650 cm^3	
머리뼈 수평둘레	Cranial circumference		558.3 mm	
얼굴 웃높이	Upper facial height	72.6 mm	68.5 mm	
얼굴 웃너비	Upper facial breadth	115.2 mm	106 mm	
얼굴 가운데너비	Mid-facial breadth	108 mm		
광대뼈 너비	Bi-zygomatic breadth	138.5 mm	145 mm	
코 너비	Nasal breadth	27.8 mm		
코 높이	Nasal height	56.5 mm		
눈확 너비	Orbital breadth	43 mm	41.5 mm	
눈확 높이	Orbital height	35 mm	35 mm	
송곳이우묵이 깊이	Canine fossa depth	2 mm		
입천정 길이	Palate length	62.3 mm	53 mm	
입천정 너비	Palate breadth	43 mm	49.2 mm	

Appendix B. Raw Data Provided for Published Korean Mandibles

북한 용어	English translation	Ryong-gok #1	Ryong-gok #2	Ryong-gok #4	Ryong-gok #5	Ryong-gok #6	Seung-risan	Geum-chun	Man-dalli
아래턱뼈 길이	Mandibular length	106.0	118.6			113.0			87.0
아래턱뼈 각너비	Angular breadth	112.3	117.5			105.0	114.0		108.4
뼈마디도드리사이너비	Bicondylar breadth					136.2			132.0
아래턱뼈 앞너비	Anterior breadth	54.3		54.2		53.0	49.8		55.5
아래턱뼈 높이 – 가운데부위	Mandibular height—midline	39.2	46.2	32.6	33.2	41.5	37.0	31.2	36.0
아래턱뼈 높이 – 턱구멍부위	Mandibular height—mandibular foramen	35.8	41.5	32.4	31.6	38.2	38.6	32.0	38.0
아래턱뼈 높이 – 첫째~둘째큰어금니사이	Mandibular height—M1–M2	35.0		28.6		37.6	32.5	31.8	34.0
아래턱뼈 높이 – 잘룩이	Mandibular height—mandibular notch					50.0			
아래턱뼈 두께 – 이음부	Mandibular thickness—midline							13.6	
아래턱뼈 두께 – 턱구멍부위	Mandibular thickness—mandibular foramen	11.5	18.2	10.6	12.0	15.2	16.0	15.0	16.0
아래턱뼈 두께 – 첫째~둘째큰어금니	Mandibular thickness—M1–M2					18.6	20.2	18.0	19.5
아래턱뼈 두께 – 둘째~셋째큰어금니	Mandibular thickness—M2–M3					23.5			19.4
아래턱뼈 두께 – 셋째큰어금니 뒤	Mandibular thickness—posterior to M3						19.0		
앞이점 – 턱밑점 거리	Chin height	39.2	46.2				37.0		
턱불룩이 사이 거리	Inter-mandibular eminence distance	41.3	49.3				40.5		
턱구멍중심–턱밑면	Mandibular foramen—inferior border	15.8	18.2			16.2	16.7		19.2
턱구멍중심–이틀면	Mandibular foramen—alveolar surface	20.0	23.3			21.0	21.0		
아래턱뼈가지 높이	Mandibular ramus height		69.6			70.5			72.0
아래턱뼈가지 너비	Mandibualr ramus breadth	39.4	43.6			50.2			
아래턱뼈가지 큰너비	Maximum ramus breadth								43.0
아래턱뼈가지 작은너비	Minimum ramus breadth								42.4
아래턱뼈 가운데 두께	Thickness of mandible	15.0							16.0
이틀앞뒤두께	Thickness of alveolar process	8.0							7.0
아래턱뼈머리길이	Mandibular condyle length					27.0			21.3
아래턱뼈머리너비	Mandibular condyle width					13.0			10.0
턱구멍직경	Mandibular foramen diameter					6.2	5.0		
아래턱잘루기 너비	Mandibular notch breadth								40.0
아래턱잘루기 깊이	Mandibular notch depth								16.5

Appendix C. Hominin Teeth Measurements

Data on Maxillary M1s, M2s, and M3s

M1s			M2s			M3s		
Specimen/Population	Buccal–Lingual (s.d.)	Mesial–Distal (s.d.)	Specimen/Population	Buccal–Lingual (s.d.)	Mesial–Distal (s.d.)	Specimen/Population	Buccal–Lingual (s.d.)	Mesial–Distal (s.d.)
A. afarensis (N = 6)	13.37 (1.18)	12.22 (0.91)	*A. afarensis* (N = 8)	14.64 (0.76)	13.11 (0.70)	*A. afarensis* (N = 13)	15.04 (1.32)	13.1 (0.98)
A. africanus (N = 9)	13.83 (0.63)	12.58 (0.36)	*A. africanus* (N = 11)	15.6 (0.76)	13.8 (0.71)	*A. africanus* (N = 12)	15.60 (1.33)	13.85 (1.30)
Early *Homo* (N = 10)	13.05 (0.88)	12.73 (0.84)	Early *Homo* (N = 6)	14.82 (1.71)	12.77 (1.03)	Early *Homo* (N = 7)	14.57 (1.54)	12.40 (0.94)
H. erectus (N = 13)	13.05 (0.86)	11.85 (0.86)	*H. erectus* (N = 14)	13.09 (0.95)	11.86 (1.10)	*H. erectus* (N = 12)	12.39 (1.32)	9.88 (0.69)
Neanderthal (N = 10)	12.72 (0.76)	12.26 (0.98)	Neanderthal (N = 17)	12.83 (0.85)	10.82 (0.89)	Neanderthal (N = 8)	12.40 (0.80)	10.20 (0.90)
Middle Palaeolithic Modern Human (N = 5)	12.80 (0.69)	11.16 (0.34)	Middle Palaeolithic Modern Human (N = 3)	12.6 (0.40)	10.93 (0.75)	Middle Palaeolithic Modern Human (N = 3)	11.77 (0.58)	10.00 (0.79)
Upper Palaeolithic Modern Human (N = 155)	12.10 (0.62)	10.60 (0.60)	Upper Palaeolithic Modern Human (N = 128)	12.30 (0.77)	10.05 (0.79)	Upper Palaeolithic Modern Human (N = 45)	11.37 (1.2)	8.90 (2.12)
Mesolithic Modern Human (N = 187)	11.90 (0.59)	10.40 (0.54)	Mesolithic Modern Human (N = 206)	11.81 (0.78)	9.62 (0.64)	Mesolithic Modern Human (N = 118)	11.41 (0.83)	8.80 (0.70)
Neolithic Modern Human (N = 157)	11.21 (0.60)	9.82 (0.53)	Neolithic Modern Human (N = 148)	10.92 (0.88)	8.99 (0.61)	Neolithic Modern Human (N = 119)	10.19 (0.90)	8.42 (0.78)
Asian Middle Pleistocene *Homo* (N = 4)	12.98 (1.37)	11.53 (1.31)						
Ryonggok Skull no. 3 (avg.)	10.75	10.3	Ryonggok Skull no. 3 (avg.)	11.2	9.5	Ryonggok Skull no. 3 (avg.)	10.7	8.2
			Dokchon Soongnisan	11.7	9.4			

(*Continued*)

Data on Mandibular m1s, m2s, and m3s

m1s			m2s			m3s		
SPECIMEN/POPULATION	BUCCAL–LINGUAL (S.D.)	MESIAL–DISTAL (S.D.)	SPECIMEN/POPULATION	BUCCAL–LINGUAL (S.D.)	MESIAL–DISTAL (S.D.)	SPECIMEN/POPULATION	BUCCAL–LINGUAL (S.D.)	MESIAL–DISTAL (S.D.)
A. afarensis (N = 9)	12.6 (0.85)	13.2 (1.043)	*A. afarensis* (N = 21)	13.39 (1.10)	14.03 (1.28)	*A. afarensis* (N = 2)	11.7 (0.57)	14 (0.85)
A. africanus (N = 11)	13.1 (1.0)	13.80 (0.87)	*A. africanus* (N = 5)	14.10 (0.87)	15.22 (1.00)	*A. africanus* (N = 7)	13.74 (0.72)	15.46 (0.93)
Early *Homo* (N = 15)	12.51 (1.16)	13.73 (0.77)	Early *Homo* (N = 6)	13.53 (1.07)	15.08 (0.98)	Early *Homo* (N = 8)	13.55 (1.13)	15.83 (1.40)
H. erectus (N = 35)	12.01 (0.98)	12.69 (0.91)	*H. erectus* (N = 32)	12.55 (0.95)	13.30 (1.01)	*H. erectus* (N = 27)	11.67 (0.86)	12.75 (1.59)
Neanderthal (N = 20)	11.20 (0.76)	11.90 (0.90)	Neanderthal (N = 20)	11.29 (0.82)	12.34 (0.93)	Neanderthal (N = 16)	10.96 (0.55)	11.97 (0.47)
Middle Palaeolithic Modern Human (N = 3)	12.03 (0.71)	12.16 (1.11)	Middle Palaeolithic Modern Human (N = 3)	11.53 (0.25)	11.27 (0.67)	Middle Palaeolithic Modern Human (N = 3)	11.37 (0.50)	12.47 (0.51)
Upper Palaeolithic Modern Human (N = 67)	10.87 (0.66)	11.45 (0.68)	Upper Palaeolithic Modern Human (N = 155)	10.97 (0.91)	11.13 (0.82)	Upper Palaeolithic Modern Human (N = 117)	10.90 (0.95)	10.95 (0.96)
Mesolithic Modern Human (N = 110)	10.98 (0.49)	11.39 (0.64)	Mesolithic Modern Human (N = 198)	10.49 (0.59)	10.65 (0.65)	Mesolithic Modern Human (N = 182)	10.23 (0.72)	10.44 (0.77)
Neolithic Modern Human (N = 176)	10.20 (0.50)	10.52 (0.56)	Neolithic Modern Human (N = 160)	9.79 (0.60)	10.11 (0.65)	Neolithic Modern Human (N = 110)	9.46 (0.72)	9.84 (0.85)
Ryonggok Mandible no. 1 (avg.)	12	11.15	Ryonggok Mandible no. 1 (avg.)	11.85	11.45	Ryonggok Mandible no. 1 (avg.)	10.5	9.8
Ryonggok Mandible no. 2 (avg.)	11.6	11.7	Ryonggok Mandible no. 2 (avg.)	11.8	11.9	Ryonggok Mandible no. 2 (avg.)	11.5	11.6
Ryonggok Mandible no. 6	12.2	11.2	Ryonggok Mandible no. 6	11.8	11.4	Ryonggok Mandible no. 6	12.2	12.1
Dokchon Soongnisan	10.5	11.6	Geumchon	11.7	12.3			
Geumchon	12.9	11.8	Mandalli	11.4	12.3			

NOTES

1. Use of the term "mid-Pleistocene *Homo*" avoids the nomenclatural baggage of "archaic *H. sapiens*." See Bae et al. 2014 and particularly Xiao et al. 2014 for discussion.
2. Here following a two-stage cultural sequence, Early and Late Palaeolithic, as defined by Gao and Norton 2002, Ikawa-Smith 1978, and Norton et al. 2009.
3. Mellars (1996) addresses similar problems with the Chatelperronean in Upper Paleolithic Europe.
4. For comparable applications, see Bae et al. 2014 and Xiao et al. 2014.
5. See Author Guidelines in the *Journal of Vertebrate Paleontology*.
6. Because the 2D data we used were extracted from 3D data, the data we present in Table 4 do not match up exactly with what are presented in the Appendix for the same measurements.
7. For varying interpretations of Northeast Asian early modern humans, see Harvati 2009, Shang et al. 2007, and Shang and Trinkaus 2010.

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ABSTRACT

Traditionally, one of the primary problems hindering a better understanding of the "origin of modern humans" debate is the paucity of information coming out of eastern Asia. Here, we report a set of hominin fossils from Ryonggok, a late Pleistocene cave site located in the paleoanthropologically poorly known region of the Democratic People's Republic of Korea. Ryonggok is best known for the presence of vertebrate fossils that represent the remains of at least five individuals. We focus our study on the two fairly well-preserved crania—#3 and #7—and analyze published dental metric data. The primary conclusion we draw from this study is that Ryonggok #3 and #7, while retaining some archaic characteristics, likely represent early modern humans. Because the earliest cultural deposits in Ryonggok appear to date to older than 40,000 years ago, it is likely that these remains may be part of the earliest dispersals of early modern humans into the area. An alternative scenario is that this is evidence of some degree of admixture between indigenous mid-Pleistocene *Homo* or possibly a late appearing *Homo erectus* and new modern human migrants to the region. Further study is necessary to determine which of these two scenarios best fits the Korean record. In addition, we present additional linear metric cranial and mandibular data for difficult-to-access North Korean fossils (e.g., Ryonggok, Mandalli, Seungrisan, Geumchun). Keywords: Korea, late Pleistocene, modern human origins, geometric morphometrics, odontometrics.