Anatomical and Histological Analyses on Cattle and Horse Bones of Joseon Period Discovered at Archaeological Site in Old Seoul City Area

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SHORT REPORT

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ABSTRACT

Anatomical examination of animal bones found at archaeological sites can provide information that historical studies alone cannot. As related in this report, we performed morphological analyses on cattle and horse bones retrieved from Joseon-period ruins found at the Gongpyeongdong site (Seoul, South Korea). By anatomical and histological comparisons, we confirmed that the slaughter of Gongpyeongdong cattle and horses was done at a later age than is the case today. This was likely due to the fact that cattle and horses in Joseon society were raised primarily as beasts of burden and only secondarily for food; and so, the Joseon government strictly prohibited what it considered to be premature slaughter.

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INTRODUCTION

In Korean history, the Joseon kingdom (1392–1910 CE) survived political turmoil and foreign invasions, thus having brought in an invaluable heritage that makes the fundamental structure of modern Korean society. In the seventeenth century, as the Joseon King, governmental offices, and military headquarters were located at Old Seoul City, the capital city became one of the most populous areas in East Asia at the time (Shin et al. 2020). This means that a lot of animals might have been slaughtered to feed a large population in the city. Such animal bones are of academic importance, because they can shed light on faunal and cultural settings in history (Sawada et al. 2014).

In South Korea, for the past decades, zooarchaeologists thus retrieved and researched ancient animal bones from archaeological sites of Joseon dynasty period. Anatomical examination was an essential component of research involving ancient animal bones, as it provides valuable insight that would be impossible to obtain by way of simple historical or archaeological studies. Zooarchaeological studies on Joseon period animal bones so far revealed that the most numerous species was cattle (67.9%), followed by horse (14.8%), dog (13.45%), deer (3.36%), pig (0.22%), river deer (0.22%), and other animal bones (Jeong 2007; Lee & Ko 2007; Ulsan Development Institute 2009; Hangang Institute of Cultural Heritage 2011; Mahan Culture Research Center 2011; Seoul Museum of History 2012; Lee et al. 2013; Research Institute of Buddhist Cultural Heritage 2016).

Among the varieties of animal bones found at excavation sites, cattle and horse remains are especially relevant to studies on past societies. During the Joseon period of Korean history (1392–1910 CE), the roles of cattle and horses in agriculture, transport, and military operations were, of course, highly valued. Premature slaughter of sub-adult cattle and horses was thus prohibited by Joseon law. Historians have argued that cattle were slaughtered only once they had become too old to work in the field (Kim 2018). This is interesting, in that it is common, in present-day South Korea, to slaughter livestock at a sub-adult stage to guarantee better meat quality and taste. The limitation of that hypothesis, however, is that it is based only on historical literature, but not on scientific evidence.

Recently, we newly excavated cattle and horse bones at an archaeological site (Gongpyeongdong) in what was the capital of Joseon kingdom: Old Seoul City. Seeking to confirm that Joseon livestock were slaughtered later than in today's practice, we estimated each bone's age anatomically and, supplementarily where necessary, by histomorphological study of bone microstructure, which was further analyzed in a more quantitative way. Although this is a simple case report on just a single archaeological case, it could prove significant considering the aforementioned lack of any scientific analysis backing up historians' hypothesis on the timing of the slaughter of Joseon-period livestock.

ARCHAEOLOGICAL INFORMATION

The Research Institute of Buddhist Cultural Heritage (Seoul, South Korea) conducted an archaeological excavation at the 15th-to-16th-century Gongpyeongdong site in Seoul City (***Figure 1A*** and ***1B***). Excavated ruins of the Gongpyeongdong site include residence, furnace, lavatory and drainage and others (***Figure 2***). Particularly animal bones were also discovered at the 15th century pits #5 and #1 situated at the layer VI of the site (Kim, Hong & Shin 2020). Cattle (*Bos taurus*) and horse (*Equus caballus*) bones were retrieved at those pits (***Figures 2*** and ***3***). Except for cattle and horse bones, no other animal bones were unearthed at the sites (Research Institute of Buddhist Cultural Heritage 2016). During the era of the Joseon Dynasty, government offices were located at the Gongpyeongdong site. In this regard, we should note that during the Joseon dynasty period, animals were periodically sacrificed in rituals led by government officials. Archaeologists have assumed that the cattle and horse bones left after the meat had been eaten were buried at the place (Kim, Hong & Shin 2020).

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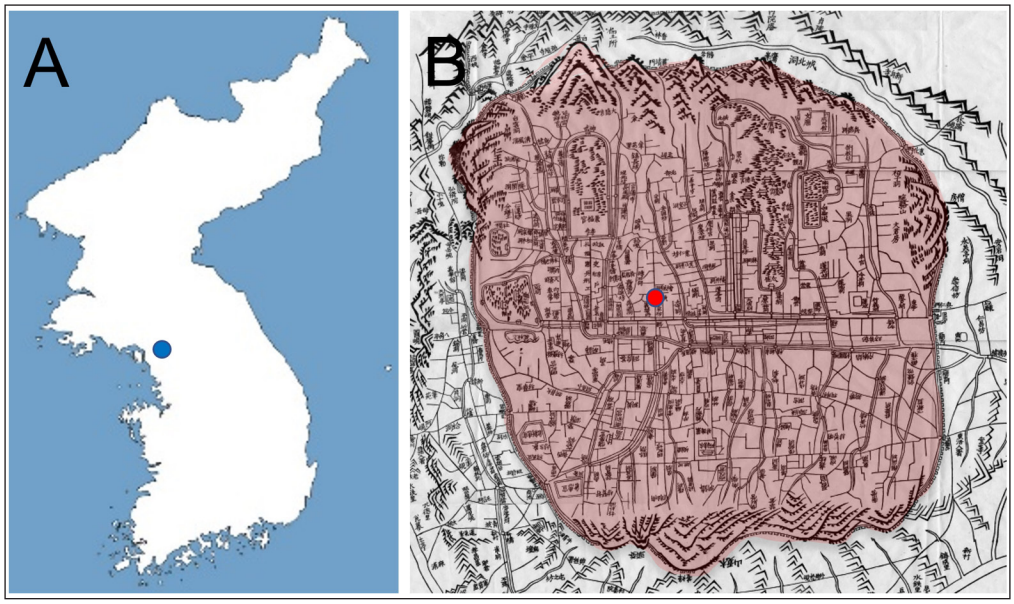

Figure 1 Location of the excavation site. **(A)** The location of Seoul City (blue dot) in Korean peninsula. **(B)** Red dot indicates Gongpyeongdong site. The red shadowed area is Old Seoul City (Hansung), the capital of Joseon Dynasty. The map is Suseonjeondo (The map of Old Seoul City) published in 1825. Courtesy of National Library of Korea.

Figure 2 The excavation site at Gongpyeongdong site. Cattle and horse bones were collected at the 15th century pits #1 (white arrow) and #5 (yellow arrow) situated at the layer VI of the excavation site.

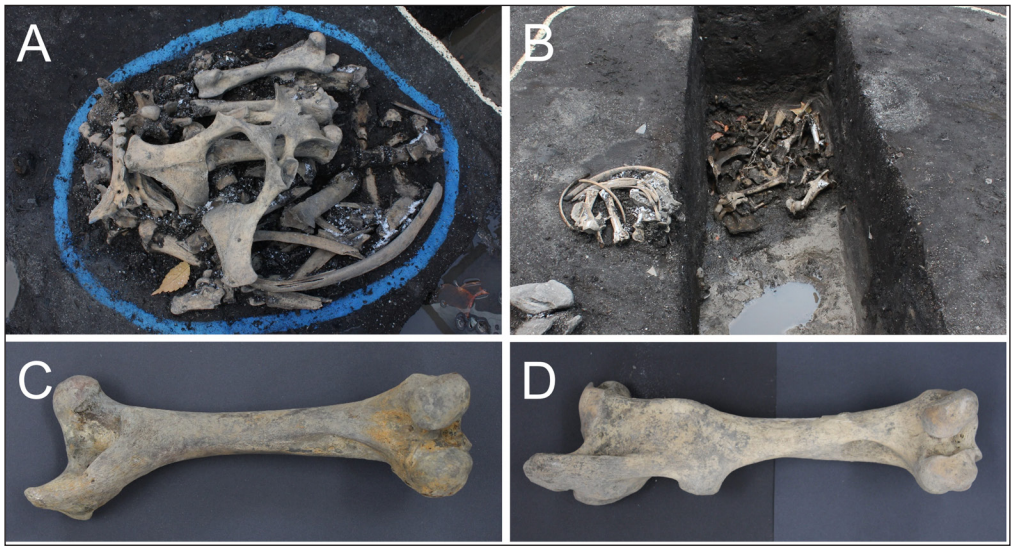

Figure 3 Cattle and horse bones found at pits **(A)** #1 and **(B)** #5. **(C)** Cattle and **(D)** horse bones examined in this study.

ANATOMICAL STUDY

The left femurs of cattle (n = 2: SNU-A005-FM1 and SNU-A005-FM2) and a horse (n = 1: SNU-A001-FM1) were selected for our examinations (***Figure 3C*** and ***3D***). We could not estimate the sex of the cattle and horse by any of the information gleaned from a gross anatomical examination of the femurs or other bones found at pits #5 and #1. We estimated the animals' age by anatomical and/or histological criteria. Specifically, age estimation typically is performed by scrutiny of epiphyseal plate fusion and ossification centers in femurs (Campbell 1977; Rudan 2009; Silver 1969). Actually, notwithstanding distinctions in accordance with breeds, epiphyseal plates are known to be fused at generally 42 months (proximal end) and 42–48 months (distal) in cattle femurs. In the case of horse femurs, both proximal and distal ends are fused at approximately 36–42 months (Silver 1969). In our cases of Gongpyeongdong cattle (SNU-A005-FM1, SNU-A005-FM2) and horse (SNU-A001-FM1), epiphyseal closure was found at the proximal and distal ends of the femur, which means that the animals were fully grown when slaughtered (***Figure 4***).

Figure 4 Epiphyseal closure observed from Gongpyeongdong cattle (SNU-A005-FM1) and horse (SNU-A001-FM1) femoral bones. Cattle: **(A)** proximal and **(B)** distal ends. Horse: **(C)** proximal and **(D)** distal ends.

For the purposes of a comparative analysis, the left femurs of present-day cattle (n = 3: BOSM-a001, BOSM-a002, BOSM-a003) and horses (n = 3: EQUM-a001, EQUM-a002, EQUM-a003) were obtained from Cheonma Mall (Cheonan, South Korea) and Daon Meat (Chuncheon, South Korea). The meat sellers confirmed that modern edible cattle and horses are slaughtered at a sub-adult stage to guarantee better meat quality and taste. They revealed that the age of modern cattle and horses are likely to be 24–30 months (juvenile) and 48–60 months (young adult), respectively. However, scientific tests were needed in order to estimate more accurate ages for them.

In a gross anatomical study, the modern cattle (BOSM-a001, BOSM-a002, BOSM-a003) showed unossified epiphysial plates and still-separated epiphysis and diaphysis (***Figures 5A*** and ***5B***). This finding fits well with the age information (juvenile) provided by the meat sellers. As for the Gongpyeongdong cattle, the contrasting appearance of their growth plates indicated conclusively that they had been slaughtered much later (after at least 24–30 months) than today's cattle typically are.

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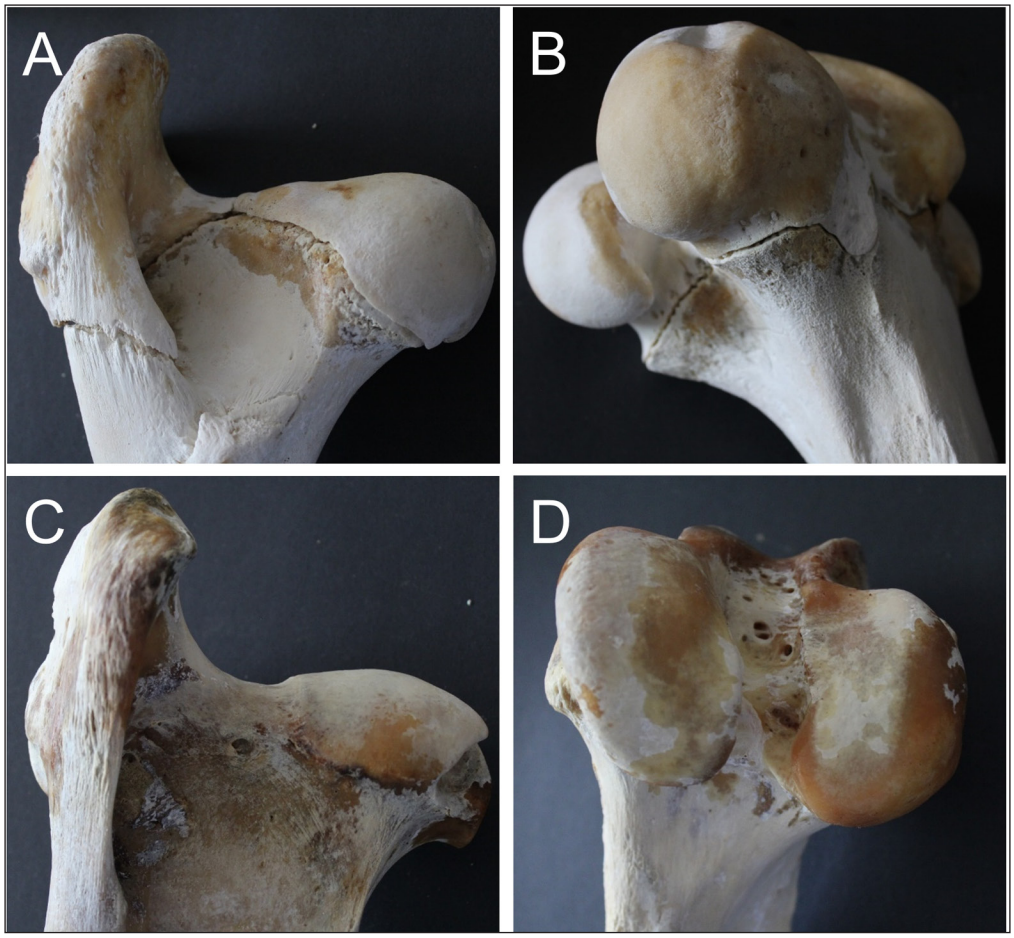

Figure 5 Epiphyseal plates of modern cattle (BOSM-a001) and horse (EQUM-a001) femurs. Cattle: **(A)** proximal and **(B)** distal ends. Horse: **(C)** proximal and **(D)** distal ends. The presence of epiphyseal plates and separation of epiphysis and diaphysis is identifiable only in (A) and (B). Growth plate fusion is seen in (C) and (D).

However, we also found that the epiphyseal plates of the modern horse (EQUM-a001, EQUM-a002, EQUM-a003) were ossified, like those of the Gongpyeongdong horse (***Figures 5C*** and ***5D***). Thus, by gross anatomy, we could not confirm whether there was a difference in age between the Gongpyeongdong and modern horses at the times of their slaughter.

HISTOLOGICAL ANALYSIS

This impasse required supplementary, histological analysis. To that end, bone sections were cut with a standard band saw. Given the archaeological meaningfulness of specimens such as the present Gongpyeongdong ones, obtainment of samples from a wide range of bones is prohibited. Sections therefore were cut at the (adequately thick) midshaft. Also, caudal sides were selected for every specimen histologically studied, due to the unavailability of any of the other quadrants (cranial, lateral, or medial). Section block thickness ranged from 3 to 4 mm.

The ancient bone samples were then embedded in epoxy resin mixture (Crescimanno & Stout 2012; La, Kim & Kim 2020). For that purpose, in brief, EpoThin™2 Epoxy Resin and Hardener (Buehler, Illinois, USA) were mixed to make resin blocks. The mixture was then poured into a mold and kept under a vacuum for an hour to remove air trapped in the resin. After 10 hours, the mixture became hardened. The modern cattle and horse bones did not require embedding; Simply, they were ground and polished to a final thickness of 60–100μm, in reference to the revised Frost's method (Beauchesne & Saunders 2006). After the thin sections were cleaned with xylene, they were then mounted on light-microscope (Olympus, JP/BH-2) slides. Microscopic images were taken using the Jenoptik ProgRes® software camera. Age estimation was carried out based on the bones' histomorphological features, according to the relevant reports (Cujipers & Lauwerier 2008; Demeter & Mátyás 1928; Enlow & Brown 1958; Mori et al. 2003; Sawada et al. 2014).

In the histology of Gongpyeongdong cattle, Haversian systems composed mainly of secondary osteons were observed in the section (***Figure 6A*** to ***6C***). This histological pattern is typical of adult cattle bones (Cujipers & Lauwerier 2008). Contrastingly, the histology of the modern cattle bones showed brick-like plexiform structures (***Figure 6D*** to ***6F***), which is

characteristic of young calves belonging to the order Artiodactyla (Martiniaková et al. 2006). Thus, the bone histology clearly re-confirmed our gross anatomical results, which had indicated that the Gongpyeongdong cattle very probably had been slaughtered later than what is common in today's practice.

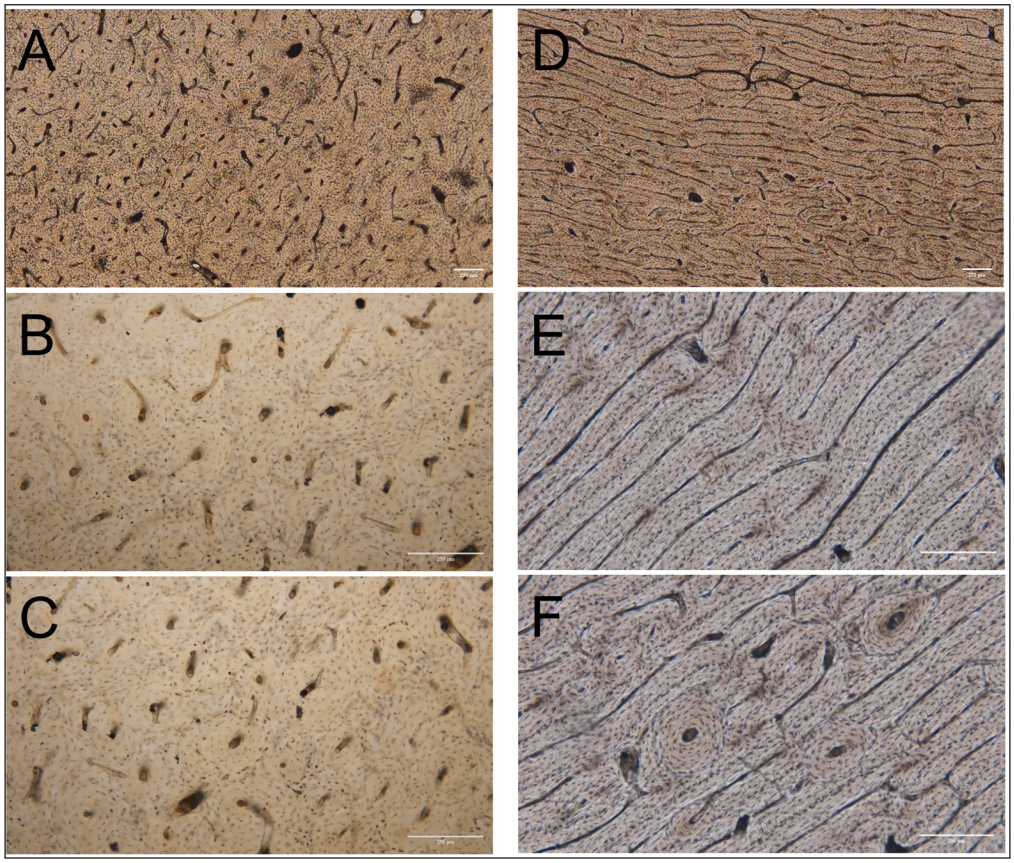

Figure 6 Histology of Joseon period and modern cattle bones. **(A)**, **(B)** and **(C)** Joseon period cattle bone. Secondary osteons are observed. **(D)**, **(E)** and **(F)** Modern cattle bones. They are mostly composed of brick-like plexiform bone structure. Scale bars = 250 μm.

As for horse bones, we could not see any difference in the growth plate fusion between the Gongpyeongdong and modern bones. However, we did observe somewhat distinct patterns in their histology. In the bone of the Gongpyeongdong horse, Haversian systems of secondary osteons were observed (***Figure 7A*** to ***7C***). In the modern horse bones by contrast, the laminar bone structure and irregular Haversian system were observed (***Figure 7D*** to ***7F***), which represents prematurity in bone histology (Zedda et al. 2008). Considering the histological results, the Gongpyeongdong horse appears to have been slaughtered at a much older age than would modern counterparts.

This trend needs to be analyzed in a more quantitative way. For quantitative image analysis, using ImageJ programs (Version 1.53e, NIH and US and Fiji version by Fiji contributors), we repeatedly counted osteon number in images of equal area size that were randomly selected from Gongpyeongdong and modern bones. In brief, osteon density refers to number of osteons on bone tissue section per square millimeter and represents the entire number of osteon remodeling events observable with resorptive bays, fragmentary and intact osteons (Frost 1987; Gocha & Agnew 2016). Osteon density was calculated because this parameter is known to change with the progression of aging (Britz et al. 2009; Dominguez & Crowder 2012; Havill 2004; Hillier & Bell 2007; Przybeck 1985). In brief, as the animals get older, the number of osteons per unit area increases further.

Table 1 and ***Figure 8*** summarize the results of osteon density measured in the bone sections of cattle and horses. Compared to the modern counterpart bones, the osteons of the Gongpyongdong cattle and horse bones are significantly larger in number per unit area, which means that the latter is much older at the time of death than the former. The pattern could be statistically confirmed by t-test implemented in R project (version 4.0.2) and PAST (PAlaeontological Statistics) software (***Table 1*** and ***Figure 8***).

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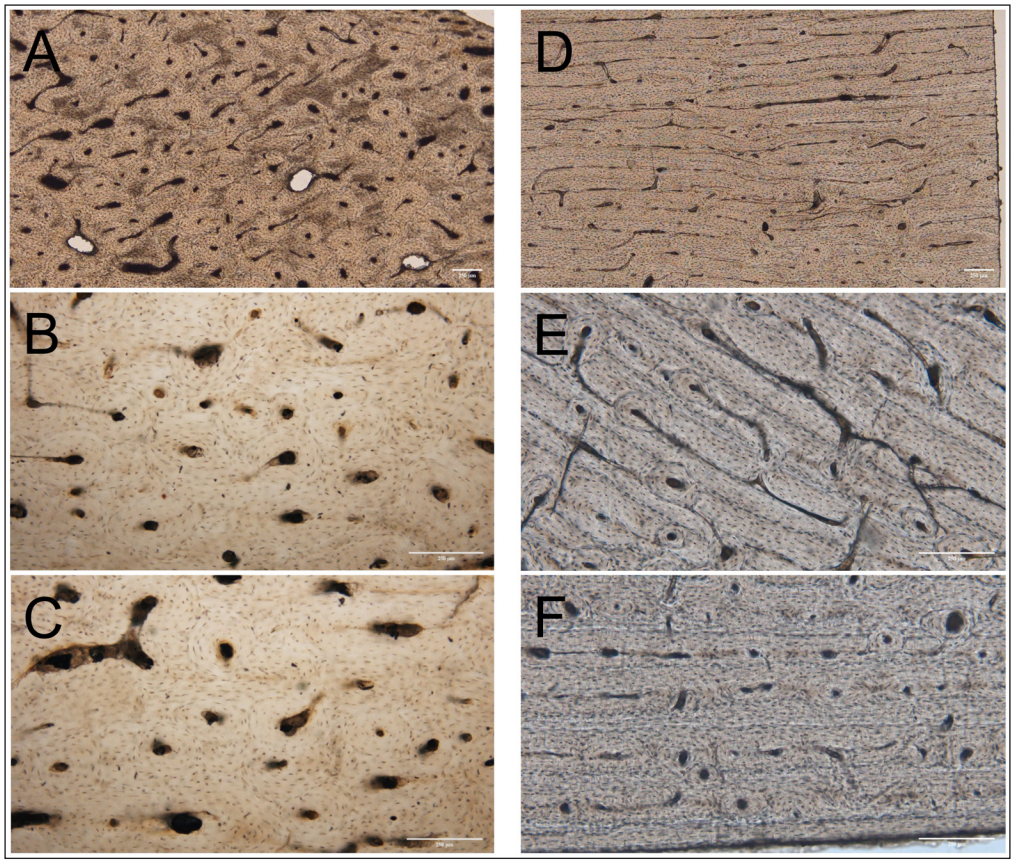

Figure 7 Histology of Joseon period and modern horse bones. **(A)**, **(B)** and **(C)** Ancient horse bone. Many secondary osteons are observed. **(D)**, **(E)** and **(F)** Modern horse bone. Laminar (fibro-lamellar complex) bone structure with primary osteons and irregular Haversian tissue could be observed. Scale bars = 250 μm.

	GONGPYEONGDONG	MODERN	*P-VALUE*
Cattle	46.2 ± 6.713	19.83 ± 5.477	3.829e–08***
Horse	43.8 ± 4.685	29.5 ± 6.688	1.791e–07***

Table 1 Statistical Analysis for Osteon Density of Cattle and Horse Bones[a].

[a] Number of measured osteons per mm^2.

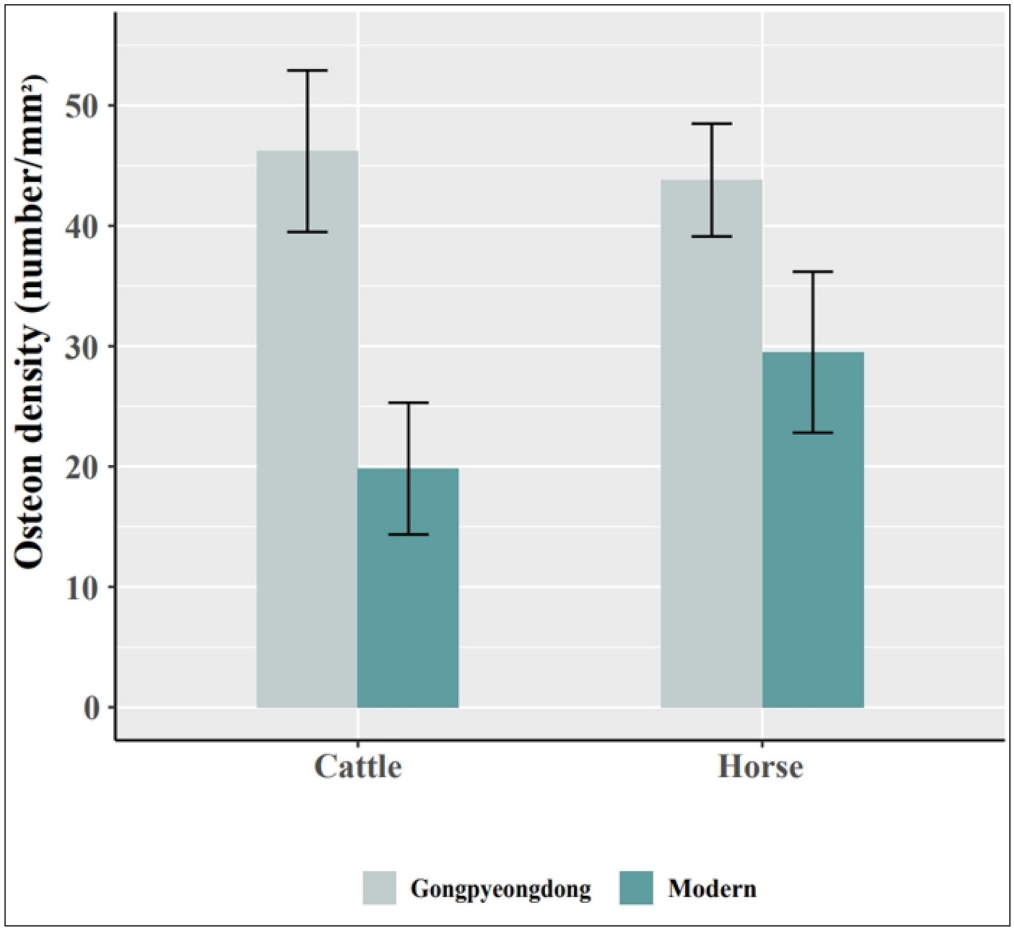

Figure 8 Bar plot of osteon density for cattle and horse bones. The measurements of Gongpyeongdong (Joseon period) and modern cases were compared.

DISCUSSION

We initially estimated the age of the Gongpyeongdong cattle and horse by anatomical criteria. Since this approach could not provide sufficient data for any definitive conclusion, we conducted a complementary histological analysis, as animal bone is known to be histologically changed with time (Cujipers & Lauwerier 2008; Demeter & Mátyás 1928; Enlow & Brown 1958; Mori et al. 2003). Put simply, bone microstructure changes from a primary to a secondary structure as an animal matures. Primary bone structure is composed of fibrous and lamellar bone with primary osteons (Cujipers & Lauwerier 2008). Fast-growing bones of juveniles or young adults manifest a plexiform or fibro-lamellar structure as well. This pattern is maintained until replacement by the secondary bone structure (Cujipers 2006; Demeter & Mátyás 1928; Enlow & Brown 1958; Mori et al. 2003). In adult bones however, the Haversian bone system, comprised mainly of secondary osteons, can be seen on histology (Cujipers & Lauwerier 2008).

In this study, the Gongpyeongdong cattle and horse showed a bone histological pattern typical of adults: a dense Haversian system with clustered secondary osteons. This means that they had been slaughtered after full maturation. This finding is in stark contrast to the sub-adult histology observed in modern bones: the plexiform structure (cattle); the pseudo-osteon, irregular Haversian tissue, the non-vascular laminar bone structure (horse), et cetera. Nevertheless, we could not rule out completely that factors other than age (e.g. physical activity level, etc.) might have influenced the histological differences between the Gongpyeongdong and modern bone samples.

As well known, there is an intervening period of industrialization between the Joseon period and modern-day Korea. This means that Korean people of both periods must have operated different ways related to raising and using domesticated animals. During the Joseon period, people raised cattle and horses mainly as beasts of burden (i.e., for farming or transportation purposes) and only secondarily as sources of meat. Accordingly, the Joseon government, for the purposes of securing a stable labor force for its agrarian society, strictly prohibited what it considered to be the premature slaughter of animals (Shin et al. 2017). Consistent with this line of thought, historians have argued that Joseon society cattle were slaughtered only when, due to age or other infirmity, they could no longer be put to farming or transportation uses (Kim 2018). Although this speculation has been generally accepted, it has not yet been confirmed scientifically. In this sense, zooarchaeology is important as it could reveal the actual pattern of ancient animal domestication. This case report, therefore, can be considered meaningful, because our data reflects a strong likelihood that Joseon-period cattle and horses were slaughtered somewhat later than are today's counterparts. Future analysis of Joseon period animal bones will allow us to solve many of similar historical mysteries that several years ago seemed unfathomable.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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