TREE-RING DATING AND AMS WIGGLE-MATCHING OF WOODEN STATUES AT NEUNGGASA TEMPLE IN SOUTH KOREA

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ABSTRACT. This paper reports the results of tree-ring dating and accelerator mass spectrometry (AMS) wiggle-matching for wooden Buddhist statues stored at the Eungjindang Hall of Neunggasa Temple, South Korea. Among 23 statues, 10 were successfully dated by tree rings. The cutting date of logs used for the statues was determined as some time between late fall 1684 and early spring 1685 when the bark ring (AD 1684) completed latewood formation. The 95.4% confidence interval of a radiocarbon date (cal AD 1688–1713, 2 σ), which was obtained by wiggle-matching 7 samples of a statue, is similar to the dendro-date (AD 1684). A historical document recorded that the statues in the Eungjindang of Neunggasa were dedicated in July 1685. The dendro-date and written record indicate that Eungjindang statues were made within 3–8 months after log cutting. This seems rather short if we consider the period required for natural drying to avoid defects such as cracking and crooking.

INTRODUCTION

Annual rings of many tree species can be used to date wooden artifacts by using dendrochronological methods (Stokes and Smiley 1968; Baillie 1984). In Korea, the wood of *Pinus densiflora* Sieb. et Zucc. (Japanese red pine, *sonamu* in Korean) was one of the most favored materials used for wooden artifacts (Park and Lee 2007). As of 2008, Japanese red pine chronologies of Korea extend back to AD 1170 and have been used for dating historic buildings, furniture, and coffins (Kim and Park 2005; Park et al. 2001, 2006, 2007). Many Korean Buddhist statues were also made of Japanese red pine.

Buddhist statues have been often dated by historical records and their styles by art historians. When these dates are controversial, it is necessary to obtain scientifically and objectively measured dates. Dendro-dates obtained by tree-ring dating can provide absolute dates of the wood materials used for the statues. However, tree-ring dating does not apply to all objects. It requires well-established master chronologies that are usually species dependent. In most regions, master chronologies are limited to a few species only. It also requires a substantial number of rings in the objects, commonly more than 70 rings. In the Buddhist statues, the number of rings is highly variable. It is also difficult to observe tree rings when the statues are gilded or finished with lacquer.

Radiocarbon dating may compliment dendrochronological dating. Specifically, wiggle-matching of ^{14}C dates (Bronk Ramsey et al. 2001), which provide highly precise dates within 15 to 30 yr (2 σ), can be very useful to date objects that cannot be dated dendrochronologically. Wiggle-matching methods are also often used to give tentative dates to floating tree-ring chronologies.

The purpose of this study is to compare AMS wiggle-matching data with tree-ring dates of Buddhist statues whose dates are already been known from historical records.

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METHODS

Eungjindang Hall of Neunggasa Temple, located in Goheung in the southern coastal area of South Korea (Figure 1), houses 23 wooden statues; a Buddha, two Bodhisattvas, Ananda, and Kasyapa in the center of the row, 8 Arhats and King Sakra on the left side, and 8 Arhats and Mahabrahmana on the right side (Figures 2 and 3). Sixteen Arhats or Buddha's disciples are housed only in Eungjindang among several buildings in Buddhist temple. The bodies of Buddha and 2 Bodhisattva statues were made of Ginkgo (*Gingko biloba* L.) wood. However, the bottoms of hollow bodies were covered with red pine panels (Figure 4), and the pedestals for these statues were also made of red pines. The other 20 statues were made of solid red pine logs (Figures 3 and 5). Due to the absence of master chronologies for Gingko species in Korea, only pines were considered for tree-ring dating.

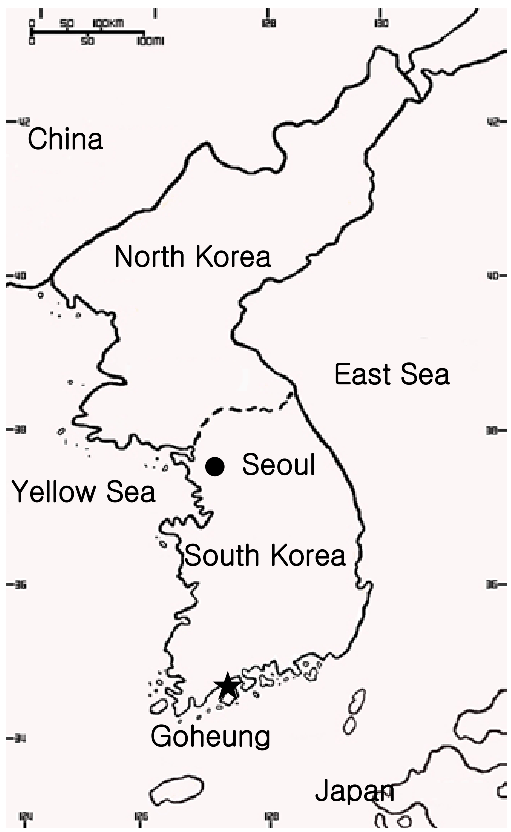

Figure 1 Location of the Neunggasa Temple (star indicates town of Goheung).

As the visible parts of statues were either gilded or painted, direct observations of tree rings were impossible. On the other hand, the bottom and pedestal parts revealed tree rings (Figures 4 and 5). Images of tree rings on the surface of unfinished parts were taken by a digital camera (Figure 5) and ring widths were measured by an image processing program.

Ring-width plots of individual statues were produced with the TSAP program (Rinn 1996) and their plots were used in visual comparison with master chronology plots on a light table for crossdating. The crossdating was also evaluated by statistical methods, *t* and *G* tests (Baillie 1984). Among den-

Figure 2 Five Buddhist statues in the center of the display

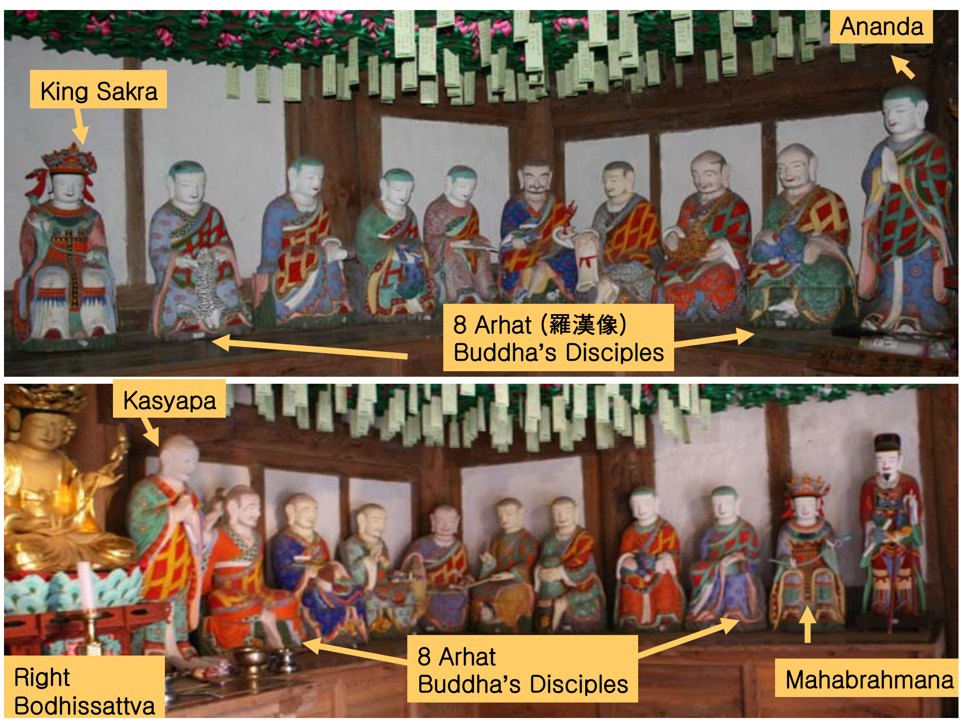

Figure 3 Flanking Buddhist statues: statues in upper panel appear to the left of the main Buddha and statues in the lower panel appear to the right.

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Figure 4 The bottom panel of Buddha statue and image of tree rings exposed on the panel (lower photo)

Figure 5 Arhat statue (left) and its bottom (lower right); photographing tree rings for measurements (upper right).

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dro-dated statues, 1 statue (Arhat # 8), which had total of 76 rings, was chosen for AMS wiggle-matching. We took 7 single-year samples from the 1st, 13th, 23th, 33rd, 53rd, 58th, and 69th rings from the innermost part, i.e. the oldest part. Single-year samples were used to minimize damage to the objects. ^{14}C measurements were performed using a Tandetron 4130 AMS of HVEE at Seoul National University. The AMS samples were pretreated by applying $NaClO_2$ after acid and base treatment, with a final acid treatment (Park 2003; Youn et al. 2007). Wiggle-matching was performed with OxCal v 3.10 (Bronk Ramsey 1995, 2001) using the IntCal04 Northern Hemisphere calibration curve (Reimer et al. 2004). The performance of wiggle-matching was determined by Bayesian statistics (Bronk Ramsey et al. 2001). The overall agreement ($A_{overall}$) is defined as a product of agreements of individual measurements, taken to a power of $1/\sqrt{n}$, where n is the number of measurements. The threshold (A_n) of acceptability for the overall agreement at 5% level for the χ^2 test is $1/\sqrt{2n}$ (Bronk Ramsey et al. 2001).

RESULTS

Tree-ring patterns of 10 statues were synchronized and a 91-yr-long composite chronology was made by averaging 10 series (Kim et al. 2009). The composite chronology crossdated well with the master chronology of Japanese red pine in South Korea (Figure 6; Kim et al. 2009). It dated back to AD 1594–1684, i.e. the last ring dated to AD 1684. The t and G values between the sample and master chronology were 5.4 ($p < 0.001$) and 67% ($p < 0.001$), respectively. Other samples could not be dated because they possessed too few tree rings (mostly, <60).

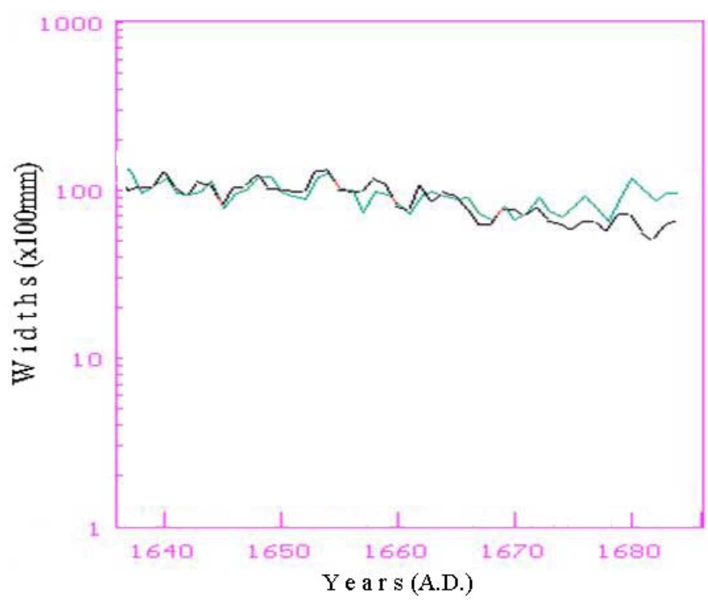

Figure 6 Ring-width plots of the master chronology (light curve) and the composite chronology of statue samples (dark curve) (the inner parts of the plots are truncated; y axis is in log scale).

The tree-ring dates for 10 statues are given in Figure 7. The Ananda and Arhat #15 statues possessed bark rings with latewood completed (AD 1684). Bark ring refers to the outermost ring with the bark present. The other 8 statues lacked bark rings. Their outermost rings dated to AD 1675–1683, indicating that some rings were removed during the carving process.

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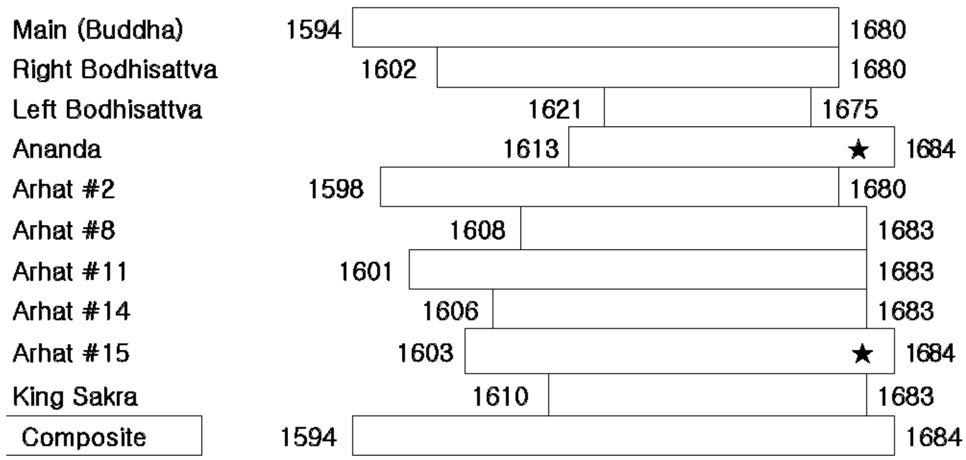

Figure 7 Tree-ring dates of 10 statues. The stars represent bark rings with the latewood completed.

Figures 8 and 9 present the probability distribution profiles of ^{14}C dates for 7 individual samples before and after wiggle-matching, respectively. Table 1 summarizes the results of ^{14}C dating. One sample (nahansang2 in Figure 9) had a poor agreement (A = 30.9%) in the wiggle-matching, but the overall agreement ($A_{overall}$: 72.7%) was highly significant because it was much higher than the threshold (A_n: 26.7%) of acceptability for the χ^2 test.

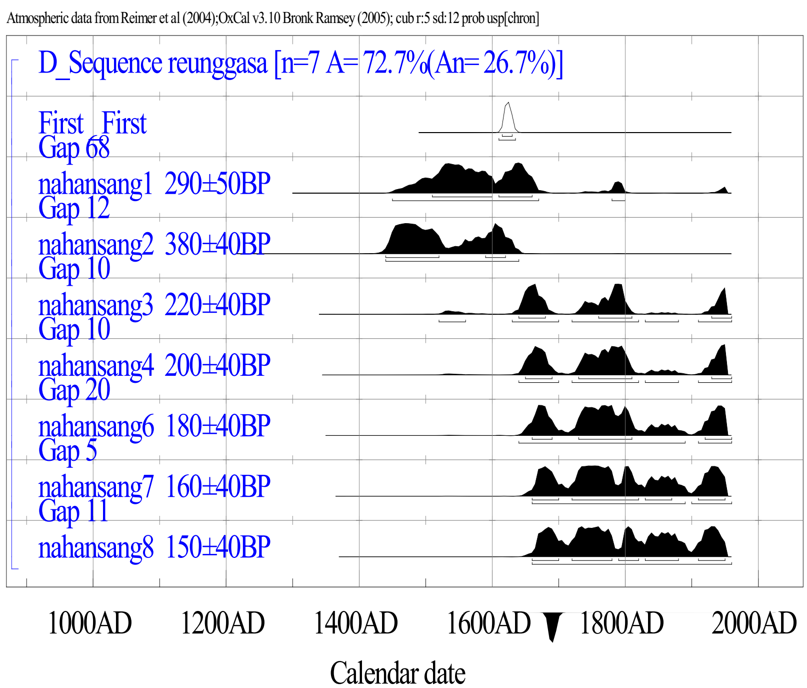

Figure 8 Probability distribution profiles of ^{14}C dates for each of 7 individual samples from the Arhat nahansang statue prior to wiggle-matching (the probability distribution of each sample is given in black profile, under which the 68.2% and 95.4% confidence intervals are designated with bars).

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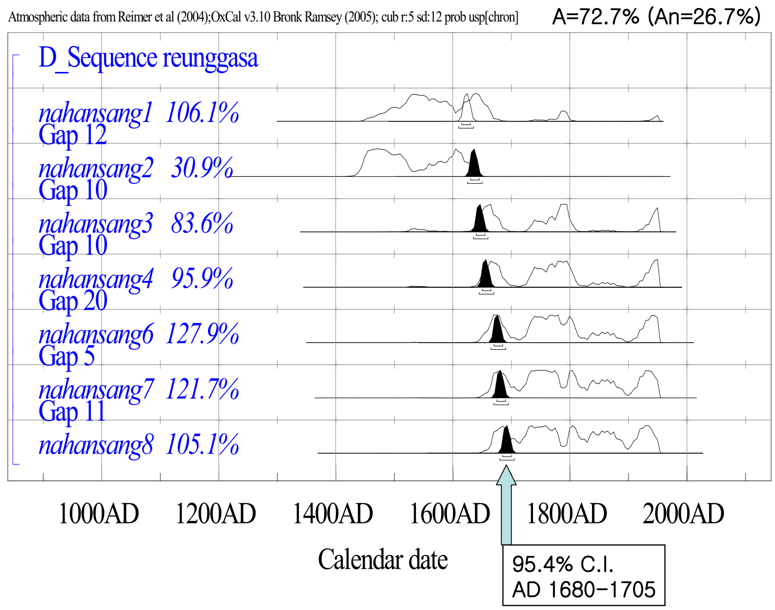

Figure 9 Probability distribution profiles (in black) of ^{14}C dates for each of the 7 individual samples from the Arhat nahansang statue after wiggle-matching.

Due to the plateau in the post-1700 period in the calibration curve, the 95.4% (2 σ) confidence intervals (CI) of individual samples prior to wiggle-matching were >300 yr (Figure 8). After wiggle-matching, they dramatically reduced to 25 yr (Figures 9 and 10). The 95.4% CI for the last sample (the 69th ring) was cal AD 1680–1705 (Table 1). Since the Arhat #8 statue used for wiggle-matching possessed a total of 76 rings, its last ring consequently dated to cal AD 1687–1712 (Table 1).

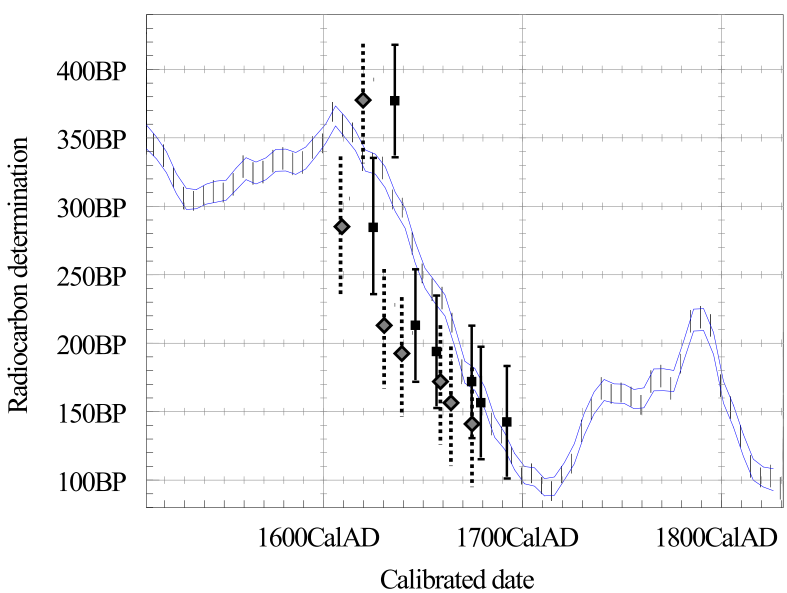

Figure 10 Measured ^{14}C data of the Arhat #8 statue (solid bars) and those corrected by dendro-dates (dotted bars) are compared with IntCal04 calibration curve.

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Table 1 ^{14}C ages and dendro-dates for the Arhat nahansang #8 statue.

Sample name	Tree-ring nr[b]	^{14}C age BP (±1 σ)	Calibrated date (cal AD)[a] 95.4% range	Mid-point	Dendro-date (AD)	Offset (^{14}C yr)
Nahansang1	1	290 ± 50	1610–1635	1622.5	1608	14.5
Nahansang2	13	380 ± 40	1625–1650	1637.5	1620	17.5
Nahansang3	23	220 ± 40	1635–1660	1647.5	1630	17.5
Nahansang4	33	200 ± 40	1645–1670	1657.5	1640	17.5
Nahansang6	53	180 ± 40	1665–1690	1675.5	1660	15.5
Nahansang7	58	160 ± 40	1670–1695	1682.5	1665	17.5
Nahansang8	69	150 ± 40	1680–1705	1692.5	1676	16.5
Last ring[c]	76	—	(1687–1712)	(1699.5)	1683	—
Bark ring[d]	(77)	—	(1688–1713)	(1700.5)	1684	—

[a]Calibrated date with wiggle-matching.
[b]Ring numbers given were counted from the innermost part, i.e. the oldest ring.
[c]^{14}C age (cal AD) of last ring in the Arhat nahansang #8 statue was calculated by adding 7 yr to the Nahansang8 age.
[d]The ^{14}C age (cal AD) of bark ring (dendro-date: AD 1684 in Figure 7) in the Arhat #15 statue was calculated by adding 8 yr to the Nahansang8 age.

DISCUSSION

We successfully dated the Neunggasa Temple statues by using both dendrochronological and ^{14}C wiggle-matching methods. The 95.4% confidence interval of the ^{14}C date (cal AD 1687–1712) of Arhat #8, which was used for wiggle-matching, did not include its dendro-date (AD 1683), but they are close enough to say they "agreed each other" if we consider the nature of ^{14}C calibration, i.e. the regional and laboratory offsets. IntCal04 calibration has been made from tree-ring samples in Europe (Irish and German oaks) and North America (Seattle Douglas-fir) (Reimer et al. 2004). The regional differences in ocean area, surface ages, and wind speeds are expected to cause ^{14}C offsets of 1‰ (8 ^{14}C yr) for most of the Northern Hemisphere (Braziunas et al. 1995, Reimer et al. 2004). Several studies indicated certain regional offsets in East Asia. The difference between Japanese tree rings and IntCal98/IntCal04 data was estimated at 30 ^{14}C yr for the period AD 80–200 (Sakamoto et al. 2003) and 14 ± 7 ^{14}C yr in the period AD 231–350 (Imamura et al. 2007). Nakamura et al. (2007) suggested a systematic offset in Japan due to ocean effects. A laboratory offset can be also a cause of the discrepancy. Laboratory offsets for the Belfast, Pretoria/Groningen, Heiderberg, and Waikato laboratories ^{14}C measurements of dendro-dated wood compared to Seattle measurements were −6 to 27 ^{14}C yr (Reimer et al. 2004). No laboratory offsets for the Seoul National University AMS facility used in this study have been measured. For the 17th century, the sum of regional/laboratory offsets and statistical uncertainty in this study was 14.5~16.5 ^{14}C yr (Table 1, Figure 10).

The 95.4% confidence intervals of ^{14}C dates of the bark rings in the Arhat #15 and Ananda statues can be calculated as cal AD 1688–1713 because the outermost ring of Arhat #8 was just 1 ring beneath the bark ring (Figure 7, Table 1). The cutting season of logs used for the statues was determined as some time from the late fall 1684 to early spring 1685 because the bark ring (AD 1684) completed the latewood. The latewood formation of Japanese red pine in Korea usually finishes in September and earlywood starts to grow in late April (Park et al. 1999). A historical document recorded that the statues in the Eungjindang of Neunggasa were dedicated in July 1685 (Choi 2006). The dendro-date and written record indicated that the Eungjindang statues were made within 3–7 months after log cutting. This seems rather short when we consider the period required for natural drying of logs to avoid defects such as cracking and crooking. Small cracks were commonly

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observed in most of the Eungjindang statues and severe ones in a few statues. It is known that slow drying during several years was a common method to avoid defects in ancient wooden artifacts of Korea (Park 2004).

If a dendro-date could be obtained, ^{14}C dating may not be necessary. In practice, however, it is better to collect samples of artifacts such as statues for both methods whenever possible. As we take only photos of the tree rings, it is very difficult to later relocate the proper rings for wiggle-matching.

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