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5년 간격 연륜의 위글매치를 이용한 정수사 법당 목부재의 방사성탄소연대 측정

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Radiocarbon Dating of a Wooden Board from Jeongsusa Temple Using Wiggle Matching of Quinquennial Tree-Ring Samples

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초 록 연륜연대로 부여된 강화 정수사 법당 목부재(풍판)의 연대를 위글매치를 이용한 방사성탄소연대 측정결과와 비교하였다. 41년(AD 1250-1290) 연륜구간에서 1250년부터 5년 간격으로 9개 연륜에 대한 방사성탄소연대를 측정하였다. 개별 연륜에 대한 방사성탄소연대의 95.4% 신뢰구간은 113.3년(평균)에 달하였는데, 위글매치 후에는 20년으로 줄어들었다. 각 연륜의 방사성탄소연대 신뢰구간이 연륜연대값을 포함하여 연대의 정확성이 입증되었다. 이 결과는 위글매치를 이용한 방사성탄소연대 측정법이 우리나라 목재문화재의 연대측정에 효율적으로 쓰일 수 있음을 제시하고 있다.

중심어: 방사성탄소, 연륜연대, 위글매치, AMS, 목재, 건축역사

ABSTRACT This paper reports the application of radiocarbon wiggle-matching for Korean wooden artifacts such as buildings and Buddhist statues for precise dating. Nine quinquennial (every five-year) samples of 41 years (AD 1250-1290) for AMS radiocarbon measurements were prepared from a wooden board used for the Main Hall at Jeongsusa (temple) in Kangwhado, Korea, which was dendrochronologically dated. The 95.4% confidence interval of radiocarbon dating prior to wiggle matching was 113.3 year in average. When wiggle-matching technique was applied, it became 20 years, 5.7 times smaller than that produced without wiggle matching. The results indicated that wiggle-matching technique using the calibration curve for northern hemisphere (IntCal04) can produce precise dates for Korean wooden artifacts, at least, for the 13th century.

Key Word: Radiocarbon, Dendrochronology, Wiggle matching, AMS, Wood, Architectural history

1. Introduction

Wooden buildings and artifacts, such as furniture and 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

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measured dates. Dendrochronological dates ('dendro date'), which are obtained by tree-ring method, can provide absolute dates of the wooden materials used for the artifacts[1-4]. However, tree-ring dating can not apply to all objects. It requires well-established master chronologies which are usually species dependent. In most regions, master chronologies are limited to a few species. It also requires substantial number of rings in the artifacts, commonly more than 70 rings.

Radiocarbon dating may compliment the dendrochronological dating. Specially, wiggle matching of radiocarbon ages provides highly precise dates as much as a range from 15 to 40 years in 95.4% confidence level($\pm 2\sigma$)[5]. Wiggles in the calibration curve for radiocarbon dating are mainly due to the variation in the solar activity, which results in the variability in atmospheric radiocarbon (C-14) concentration (refer to Figure 1 in this paper). Radiocarbons are mainly produced by neutrons, which are secondary products of cosmic rays radiated from the sun, with bombarding nitrogen molecules at altitude of about 9,000m in the atmosphere. Wiggles in calibration curve produce large errors in radiocarbon dating in addition to the measurement and statistical errors because it violates the assumption of radiocarbon dating, 'the concentration of radiocarbon in the atmosphere, i.e., the level of C14 before decaying, is constant throughout the time'. Ironically, however, we can utilize this wiggle in order to reduce the errors of radiocarbon dating by using the wiggle-matching method.

Wiggle matching is the technique which calibrates the radiocarbon ages of a series of samples in one object with certain intervals, i.e., every two, five or ten[5]. Matching the multiple results to the wiggles in the calibration curve can effectively reduce the errors in radiocarbon dating (refer to Figure 4). Therefore, wiggle matching would be very useful to date the artifacts which can not be dated with dendrochronological method. In many cases, the numbers of tree rings in the artifacts are limited. In the previous study, we applied wiggle matching to the biannual samples for 20 tree rings and decadal samples for 70 tree rings[6,7]. In the present study, we assume that 40 tree rings are available from an artifact and applying quinquennial (i.e., every five-year) samples for wiggle matching.

The objectives of this paper are to compare the radiocarbon dates obtained by wiggle matching of quinquennial samples with tree-ring dates and to know how much the wiggle matching can reduce the errors associated with radiocarbon dating.

2. Methods

A wood board (gable) used for the Main Hall of Jeongsusa (Buddhist temple) in Kangwhado, which was dendrochronologically dated, was chosen for radiocarbon dating using wiggle-matching method. Dendrochronological dating for the Main Hall of Jeongsusa, which was built in AD 1426 and repaired in 1689, was conducted[8]. A board (JS504), which was made of red pine (*Pinus densiflora* S. et Z.) contains total of 175 rings from AD 1224 to 1398[8]. From the tree-ring block with an age range of 41 years (AD 1250-1290), we took 9 quinquennial samples, i.e., the rings of AD 1250, 1255, 1260, 1265, 1270, 1275, 1280, 1285 and 1290. The radiocarbon measurements were conducted using a 1MV Tandetron AMS (accelerator mass spectrometry) of HVEE at Korea Institute of Geoscience and Mineral Resources (KIGAM)[7]. The AMS samples were pretreated by α-cellulose extraction method followed by the normal ABA (acid, base and final acid treatment) method[9].

Wiggle matching was performed by OxCal v3.10 program, which are using IntCal04 calibration curve for northern hemisphere.[5,10] The performance of wiggle matching was determined by Bayesian statistics[10]. 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 number of measurement. The threshold (A_n) of acceptability for the overall agreement at 5% level for χ^2 test is $1/\sqrt{2n}$.

3. Results and Discussion

Due to the wiggles in the calibration curve, the 95.4% confidence intervals (C.I.) of individual samples prior to wiggle matching were mostly larger than 100 years (Table 1). Figure 1 demonstrates the large errors associated with single measurements as an example of the A.D. 1250; the 95.4% C.I. was 160 years (A.D. 1050-1080 and A.D. 1150-

1280). The probability-distribution profiles of radiocarbon dates for all of 9 single samples produced without wiggle matching are given in Figure 2. The 95.4% C.I. of 9 single-samples was 113.3 years in average (Table 1). After wiggle matching, it reduced to 20 years, which is only 17.7% of those without wiggle matching (Table 1). The overall

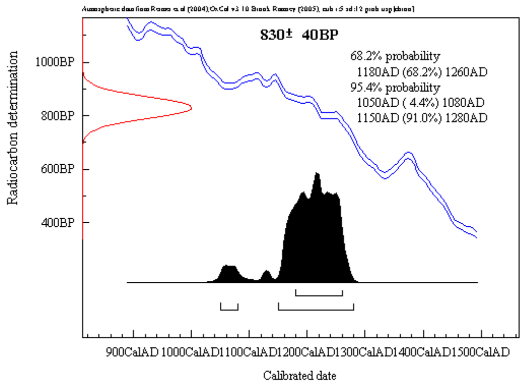

Figure 1. Probability profiles of radiocarbon date (Y-axis) and calibrated date (X-axis) for the single ring of A.D. 1250 (the calibration curve is given with ±1σ in diagonal direction; the peak on Y-axis is the probability distribution of radiocarbon measurement and the black areas represent the probability distribution of radiocarbon date after calibration; the 68.2% and 95.4% confidence intervals of the calibrated radiocarbon age are given in bars below the black area; BP: before present, the year from A.D. 1950).

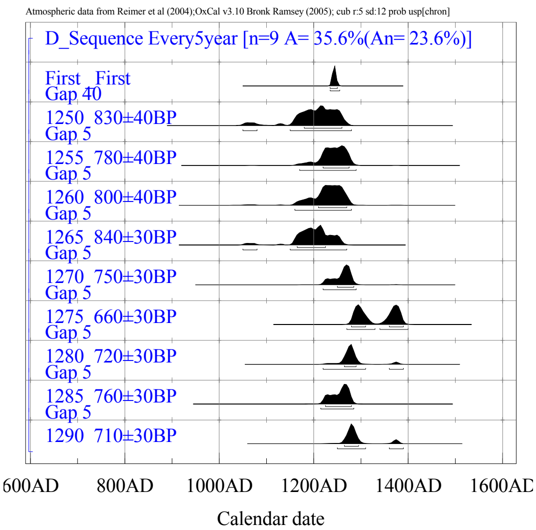

Figure 2. Profiles of probability distributions of radiocarbon dates for nine individual rings prior to wiggle matching (See Figure 1 for abbreviations).

agreement ($A_{overall}$: 35.6 %) determined by Bayesian statistics for the wiggle matching was significant because it is higher than the threshold (A_n: 23.64%) of acceptability for χ^2 test.

Figure 3 presents the probability-distribution profiles of radiocarbon dates for 9 single samples, produced by wiggle matching. The span of 95.4% C.I. for the first sample, i.e., A.D. 1250 ring was 20 years (AD 1235-1255, Figure 3 and Table 1). Those of the other samples were 20 years, too. Figure 4 shows the scheme of wiggle matching for 9 quinquennial samples fit to the calibration curve for northern hemisphere (IntCal04). The radiocarbon dates of three samples was out of error range in the IntCal04 curve. However, other 6 samples were well fit to the IntCal04 curve. Table 1 summarizes the results of radiocarbon dating before and after wiggle matching.

In the previous studies which applied wiggle matching to the biannual or decadal samples[6,7], the 95.4% C.I. produced by wiggle matching was 30 to 40 years, so they were much larger than that of the present study, 20 years. We think that quinquennial samples are better than biannual or decadal samples for wiggle matching.

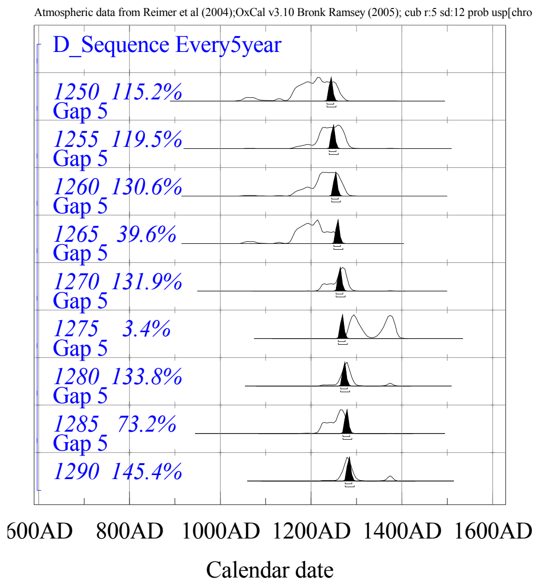

Figure 3. Profiles of probability distributions of radiocarbon dates for 9 individual rings after wiggle matching (black colored); those prior to wiggle matching which are shown in Figure 2 are given in white colored profiles.

Table 1. The results of radiocarbon dating before and after wiggle matching.

Dendro Date(A.D)	95.4% C.I. before wiggle match			95.4% C.I. after wiggle match	
	Interval(A.D.)		Span(Year)	Interval(A.D.)	Span(Year)
1250	1050-1080	1150-1280	160	1235-1255	20
1255	1170-1290		120	1240-1260	20
1260	1160-1280		120	1245-1265	20
1265	1050-1080	1150-1270	150	1250-1270	20
1270	1220-1290		70	1255-1275	20
1275	1270-1330	1340-1400	120	1260-1280	20
1280	1220-1310	1360-1390	120	1265-1285	20
1285	1215-1285		70	1270-1290	20
1290	1250-1310	1360-1390	90	1275-1295	20
Average(year)	113.3		113.3	Average(year)	20
Standard deviation	31.6		31.6	Stand. deviation	-

*C.I.: confidence interval

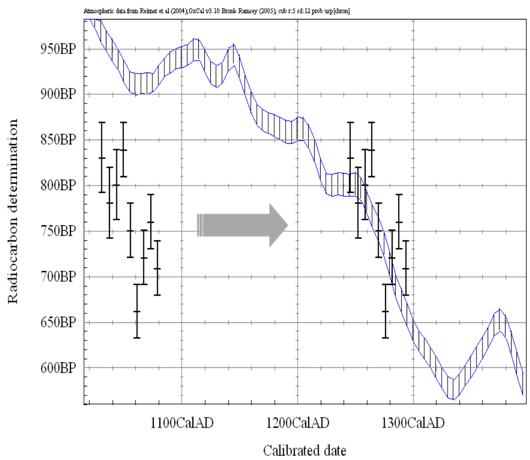

Figure 4. Schematic diagram showing AMS wiggle matching for 9 quinquennial rings of Jeongsusa temple (Left error bars represent the results of 9 quinquennial radiocarbon measurements and right ones the most probable position in the calibration curve when we take into account of 9 dates in consecutive series; the IntCal04 calibration curve is given with ±1σ in shaded area).

If dendrochronological date could be obtained, radiocarbon date may not be necessary. For the wooden artifacts, however, it is better to collect the samples together for both methods whenever possible because the probability of success in dendrochronological dating is only about 50 to 70 percents, depending on the sites and species. It is very difficult to relocate proper rings later for wiggle matching because we take only photos of tree-ring image from the surface of wooden artifacts such as furniture and statues for non-destructive sampling. Indeed, it is not an easy task to obtain sampling permission again from museum or temple officers, too.

4. Conclusion

We applied radiocarbon wiggle-matching techniques to the 9 quinquennial rings of a wooden element (gable) from the Main Hall at Jeongsusa using IntCal04 calibration curve. The sampled range was 41 years (AD 1250-1290). The 95.4% confidence intervals obtained by wiggle matching were 20 years, which was much smaller than 113.3 years produced by single measurements. All radiocarbon date of wiggle-matched 9 samples included their dendro dates. The results indicated that wiggle-matching technique using the calibration curve for northern hemisphere (IntCal04) for quinquennial samples of 41 years can produce precise dates for Korean wooden artifacts, at least, for the 13^{th} century.

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