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Wiggle Matching for Radiocarbon Dating Korean Artifacts with Biannual Samples

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ABSTRACT

This paper reports the application of radiocarbon wiggle matching for Korean wooden artifacts such as furniture and Buddhist statues for precise dating. Ten biannual samples of 20 years (AD 1249-1268) for AMS (accelerator mass spectrometry) radiocarbon measurements were prepared from a board of the pedestal for Buddhist statue at Jeongsusa (temple) in Kangwhado, Korea, which was dendrochronologically dated. The average 95.4% confidence interval of radiocarbon dating without wiggle matching was 123 year. When wiggle matching technique was applied, it became 37 year, 3.3 times smaller than that without wiggle matching. The results indicated that wiggle matching technique using the calibration curve for northern hemisphere (IntCal04: International radiocarbon calibration curve announced in 2004) can produce precise dates for Korean wooden artifacts which possess as much as 20 tree rings.

Keywords : dendrochronology, radiocarbon dating, art history, wiggle matching, tree ring.

1. INTRODUCTION

Wooden artifacts, such as furniture and 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. Dendrochronological dates (‘dendro date’), which are obtained by tree-ring method, can provide absolute dates of the wooden materials used for the artifacts (Stokes and Smiley 1968; Baillie 1984; Kim and Park 2005; Park et al. 2007). 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 40 rings. In the artifacts such as furniture, the number of rings varies much. It is impossible to measure tree rings when the furniture are gilded or finished with lacquer, too.

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 30 years in 95.4% confidence level (±2σ: σ=standard deviation) (Ramsey 2001). 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 Fig. 4 in this paper).

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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 carbon 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 years (Ramsey 2001). Matching the multiple results to the wiggles in the calibration curve can effectively reduce the errors in radiocarbon dating (refer to Fig. 5). 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 this study, we assume that only 20 tree rings are available from an artifact.

The objectives of this paper are to compare the radiocarbon dates obtained by wiggle matching with tree-ring dates and to know how much the wiggle matching can reduce the errors associated with radiocarbon dating. Finally, we will discuss whether wiggle matching technique using the calibration curve for northern hemisphere (IntCal04: International radiocarbon calibration curve announced in 2004: Reimer et al. 2004) can produce precise dates for wooden artifacts in Korean peninsula. For Southern Hemisphere and marine samples, another calibration curve (Marine04) is provided by adjusting reservoir effects of oceans (Reimer et al. 2004).

2. MATERIAL and METHODS

A board of pedestal for the Buddhist statue of Jeongsusa (temple) in Kangwhado, which was dendrochronologically dated, was chosen for wiggle matching. The board contains total of 175 rings from A.D. 1224 to 1398. From the tree-ring block with a age range of 20 years (A.D. 1249-1268), we took 10 biannual samples, i.e., 1249, 1251, 1253, 1255, 1257, 1259, 1261, 1263, 1265 and 1267 (Fig. 1). The radiocarbon measurements were conducted using a 1MV (megavolt) Tandetron AMS (accelerator mass spectrometry) of HVEE (High Voltage Engineering Europe) at Korea Institute of Geoscience and Mineral Resources (KIGAM). The AMS samples were pretreated by α-cellulose extraction method followed by the normal ABA (acid, base and final acid treatment) method (Park 2003; Youn 2007).

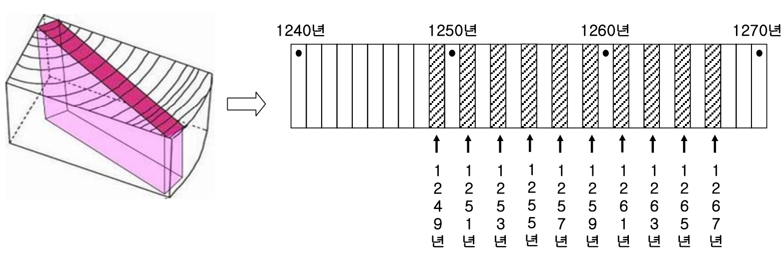

Fig. 1. Schematic diagram of sampling for wiggle matching.

Wiggle matching was performed by OxCal (University of Oxford Calibration) v3.10 program, which are using IntCal04 calibration curve for northern hemisphere (Ramsey 2001; Ramsey et al. 2001; Reimer et al. 2004). The performance of wiggle matching was determined by Bayesian statistics (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 number of measurements. The threshold (A_n) of acceptability for the overall agreement at 5% level for χ^2 (chi-square) test is $1/\sqrt{2n}$ (Ramsey et al. 2001).

3. RESULTS and DISCUSSION

Figure 2 and Figure 3 present the probability-distribution profiles of radiocarbon dates for 10 individual samples before and after wiggle matching, respectively. Table 1 summarizes the results of radiocarbon dating. The overall agreement ($A_{overall}$: 94.9 %) in the results of wiggle matching was highly significant because it is much higher than the threshold (A_n: 22.4%) of acceptability for χ^2 test.

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

Dendro Date (A.D)	Radiocarbon Date (BP±1σ)	95.4% Confidence Interval			
		Before wiggle matching		After wiggle matching	
		Interval (A.D.)	Span (Year)	Interval (A.D.)	Span (Year)
1249	840±30	1050-1080, 1150-1270	150	1210-1250	40
1251	810±30	1150-1280	130	1215-1250	35
1253	740±40	1210-1300, 1360-1390	120	1215-1250	35
1255	780±40	1170-1290	120	1215-1255	40
1257	780±40	1170-1290	120	1220-1255	35
1259	780±40	1170-1290	120	1220-1260	40
1261	810±40	1150-1280	130	1225-1260	35
1263	830±30	1150-1270	120	1225-1260	35
1265	840±30	1050-1080, 1150-1270	150	1225-1265	40
1267	760±30	1215-1285	70	1230-1265	35
Average(year)			123		37
Standard deviation			22.1		2.6

*BP: before present (age from A.D. 1950)

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 4 demonstrates the large errors associated in single measurements; for example, the 95.4% C.I. was 150 years (A.D. 1050-1080 and A.D. 1150-1270) for the A.D. 1249 sample.

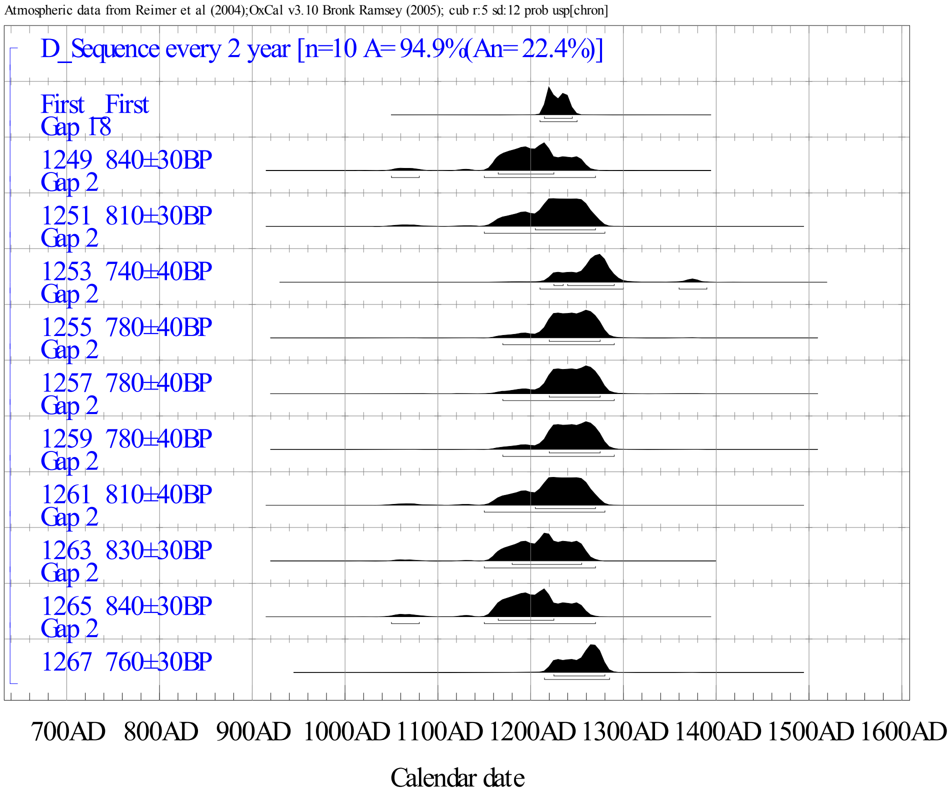

Fig. 2. Profiles of probability distributions of radiocarbon dates for ten individual samples prior to wiggle matching (BP: before present, the age from A.D. 1950); the probability distribution of each sample is given in black profile, under which 68.2% and 95.4% confidence intervals are designated with bars, respectively. The top profile showed the probability distribution for the first sample (A.D. 1249) after wiggle matching. On the left, dendrochronological dates and radiocarbon dates (with ±1 standard deviation) are given, BP: before present (age from A.D. 1950). Overall agreement (A) and threshold (A_n) of acceptability for χ^2 (chi-square) test is shown on the first line.

The 95.4% C.I. of 10 samples was 123 years in average. After wiggle matching, it reduced to 37 years in average, which is only 30% of those without wiggle matching (Figure 3 and Table 1). The span of 95.4% C.I. for the A.D. 1249 sample was 40 years (AD 1210-1250, Table 1). Figure 5 shows the scheme of wiggle matching for ten biannual samples to the calibration curve for northern hemisphere (IntCal04). The radiocarbon date (760BP±30 years) of A.D. 1257 made a crucial role to fix the ten multiple results to the calibration curve around in A.D. 1250-1270 because several results were measured older, i.e., the error bars sit above the calibration curve (Figure 5).

The 95.4% confidence intervals of ten radiocarbon dates were reduced to 35 year or 40 years by the wiggle matching. However, only those of four samples among ten included their dendro dates (AD 1249, 1255, 1259 and 1265). The 95.4% C.I. of other six samples (AD. 1251, 1253, 1257, 1261, 1263 and 1267) missed marginally their dendro dates (one to three years). We think that they are close enough to say 'agreed each other' if we consider the nature of radiocarbon calibration.

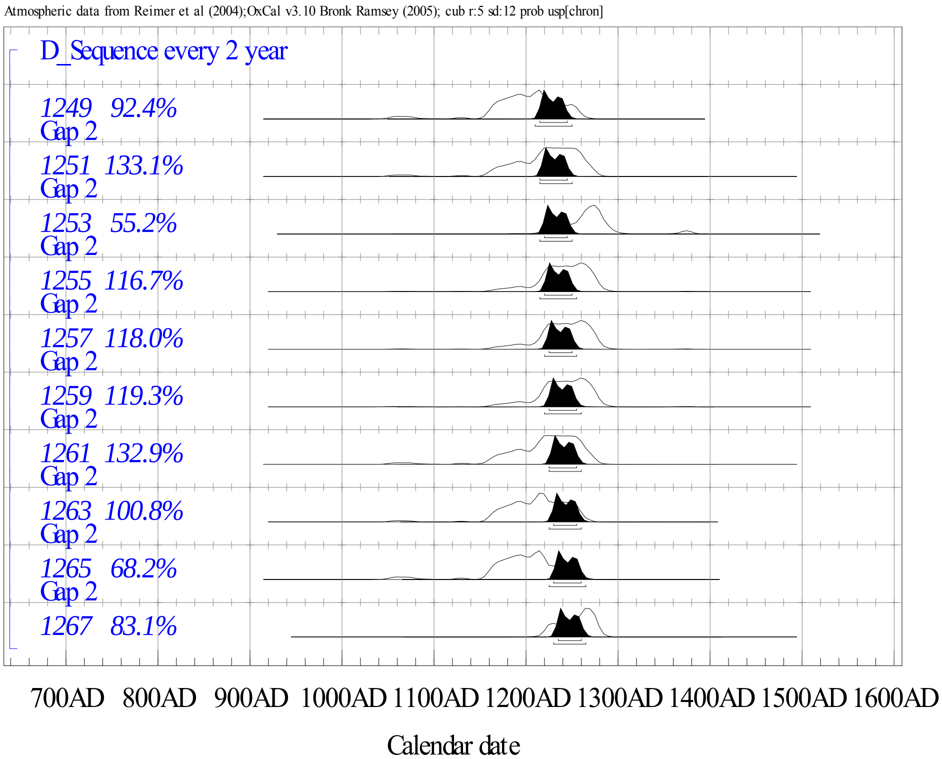

Fig. 3. Profiles of probability distributions of radiocarbon dates for ten individual samples after (black colored ones) and before wiggle matching (blank ones); the 68.2% and 95.4% confidence intervals after wiggle matching are designated by bars under each profile, respectively. On the left, dendrochronological dates and agreement statistics (A%) of each wiggle matched date with original (i.e. without wiggle matching) probability are given.

If dendrochronological date could be obtained, radiocarbon dating may not be necessary. In practice, however, it is better to collect the samples together for both methods whenever possible. In reality, the probability of success in dendrochronological dating is about 30 to 70 percents, depending on the sites and species. It is also very difficult to relocate later proper rings for wiggle matching because we take only photos of tree-ring image from the surface of 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.

Wiggle matching is not so often used for the studies on cultural artifacts and excavated objects because it costs 6 to 8 times expenses, depending on the number of samples per one specimen. It still needs much heavier destruction of the artifacts during sampling than a single measurement, though AMS requires only 10-50mg wood samples. It is also not easy task to find proper sampling location for 6 to 8 samples from an artifact. In addition, it is necessary to expose tree rings by sanding or smoothing the surface to locate proper samples. High precision of wiggle matching should offset these disadvantages to be applied for the artifacts.

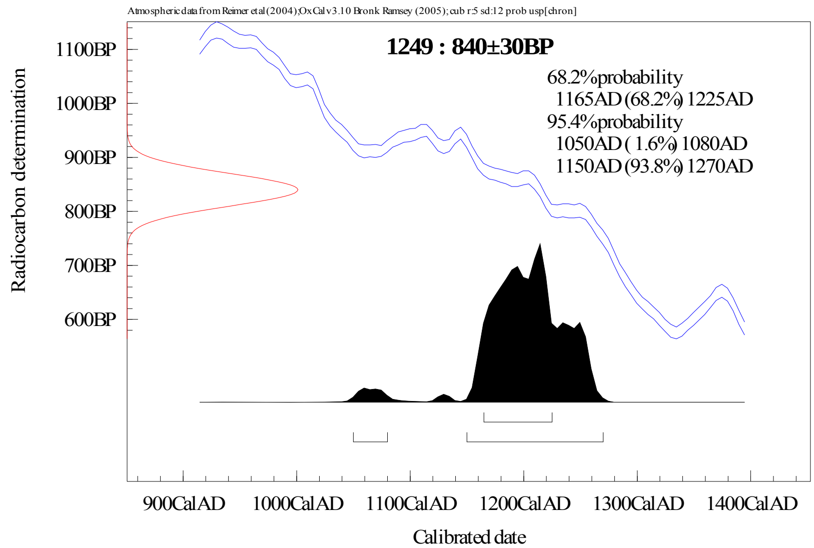

Fig. 4. Probability profiles of radiocarbon date (Y-axis) and calibrated date (X-axis) for the single sample of A.D. 1249 (the calibration curve is given with ±1σ in the diagonal direction; the peak on Y-axis is the probability distribution of radiocarbon measurement and the black areas on X-axis represent the probability distribution of radiocarbon date after calibration; the 68.2% and 95.4% confidence intervals of the calibrated radiocarbon age are given below the black area, respectively).

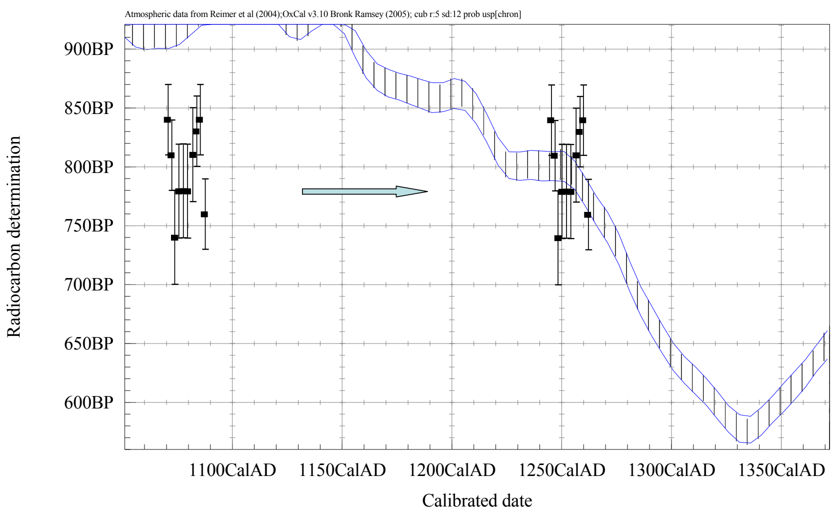

Fig. 5. Schematic diagram of wiggle matching for ten biannual samples of Jeongsusa temple (X-axis: calendar year, i.e., dendrochronological dates; Y-axis: radiocarbon dates given in BP, before present, the age from A.D. 1950); error bars on the left represent the results of ten biannual radiocarbon measurements and right ones the most probable position on the calibration curve when we take into account of ten dates in consecutive series, i.e., by wiggle matching; the IntCal04 calibration curve is given with ±1σ in shaded area).

4. CONCLUSION

We successfully applied wiggle matching technique to a board of the pedestal for Buddhist statue at Jeongsusa by measuring ten biannual samples of 20 years (A.D. 1249-1268). The 95.4% confidence intervals of radiocarbon dates were reduced to 35 year or 40 years by the wiggle matching. It is 3.3 times smaller than that without wiggle matching. The results indicated that wiggle matching technique using the calibration curve for northern hemisphere (IntCal04) for biannual samples of twenty years can produce precise dates for Korean wooden artifacts.

We cannot apply dendrochronological dating to the samples which possess small number of tree rings. They should normally have at least 40 rings. This study indicated that wiggle matching of radiocarbon dates can be an alternative to the dendrochronological dating for the small samples which include as much as 20 rings.

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