*Dental Materials Journal 2011; 30(3): 374–383*

# Factors associated with the longevity of resin composite restorations

Shisei KUBO[1], Aya KAWASAKI[2] and Yoshihiko HAYASHI[2]

[1]Center for Clinical Education and Training, Nagasaki University Hospital, 1-7-1 Sakamoto, Nagasaki 852-8588, Japan
[2]Department of Cariology, Nagasaki University Graduate School of Biomedical Sciences, 1-7-1 Sakamoto, Nagasaki 852-8588, Japan
Corresponding author, Shisei KUBO; E-mail: kubo@nagasaki-u.ac.jp

This study investigated factors associated with the longevity of resin composite restorations, which were placed in 97 patients (mean age of 58 years) by 24 dentists in Nagasaki University Hospital between 1995 and 2005. All patients were under the charge of the principal investigator (SK) and most of them had been regularly checked up for up to 11 years. A total of 503 resin composite restorations (433 by SK and 70 by the other dentists) were analyzed by the Kaplan-Meier and the Cox proportional hazards model. Ten-year survival rates were 84.2% for SK and 71.8% for the others, showing a significant difference. Although the retreatment risk had a great influence on the survival time, gender and age at placement did not have. There were no significant differences in survival between conventional 2-step etch-and-rinse, 2-step self-etch adhesives with and without prior enamel etching. Cavity type had a significant influence, whereas tooth type had no effect.

*Keywords*: Factor, Longevity, Resin composite, Retrospective study, Survival analysis

## INTRODUCTION

Good long-term clinical performance of restorations will enhance the general health and satisfaction of patients. Therefore, it is of interest and important for patients, dentists and funding agencies to know the longevity of dental restorations[1,2]. In addition, there has been an increasing emphasis on an evidence-based approach to clinical care and treatment since the middle of the 1990s[1]. Laboratory studies produce meaningful results for relatively short periods of time and can also evaluate the effect of a single variable, while keeping all other variables constant[3]. However, laboratory studies do not always reflect the clinical behavior of the material because of the differences between laboratory and clinical conditions[3]. It has been reported that the longevity of restorations is dependent on many factors such as those associated with the patient, operator, material and tooth[2,4-16].

Randomized controlled trials (RCTs) provide a high level of evidence for longevity of dental restorations[1]. However, such prospective studies may not reflect the real-life survival of restorations in general dental practice or daily living since they include many biases such as operator- and patient-related factors[1,2,4-6]. This is supported by the fact that secondary caries rarely occurred in many prospective studies[13-21], although it is the principal reason for failure of restorations in general practice[4-7,22-24]. In addition, prospective studies require many years with regular recalls in order to achieve sufficient clinical validation. During this period, restorative materials used will probably be replaced by successors or become unavailable. Therefore, useful long-term clinical trials are limited in number. For Class I and/or II resin composite restorations, more papers on long-term prospective studies have been published[12-14,17,18,25,26]. For Class III restorations, only a few articles are available[27,28]. With respect to Class V restorations, although several studies have been reported[15,16,20,21], resin composites were placed mainly in non-carious lesions (NCCLs).

In these circumstances, although retrospective studies are less defined than prospective ones, they have certain advantages in that many restorations can be examined in a relatively short time and more clinicians and patients are involved[4-6]. This may compensate for possible flaws and failures due to the method of data acquisition. Regarding survival analysis, it can deal with censored cases (*i.e.*, those which are 'unknown' due, for example, to patients not returning for recall) and estimate survival rates of restorations at a given time. Another advantage of survival analysis is that it does not require a simultaneous entry time for participants. In addition, a multivariate analysis can evaluate the effect of two or more metric and/or non-metric variables on survival and correct for confounding.

The purposes of this retrospective longitudinal study in conjunction with survival analysis were to evaluate the longevity of resin composite restorations in various cavity types and to investigate potential factors contributing to their longevity.

## MATERIALS AND METHODS

Restorations placed in patients, who were under the charge of the principal investigator (SK), were examined by SK from April 2005 to March 2006. The restorations were rated clinically acceptable, clinically unacceptable or already replaced according to slightly modified USPHS criteria (Table 1)[29-31]. In order to reduce selection bias, no consideration was taken of caries activity, the periodontal condition or parafunctional habits. A recall program had been established since 1995 and 74.2% of the patients have regularly attended for more than 5

The first two authors contributed equally to this work.

Received Nov 22, 2010: Accepted Feb 10, 2011
doi:10.4012/dmj.2010-191 JOI JST.JSTAGE/dmj/2010-191

Table 1 Modified USPHS criteria for direct clinical evaluation

| Category | Rating scale Acceptable | Rating scale Unacceptable | Criteria |
|---|---|---|---|
| Retention | A | | Retained |
| | | C | Missing |
| Recurrent caries | A | | None |
| | | C | Present |
| Marginal staining | A | | None |
| | B | | Superficial staining (removable, localized) |
| | | C | Deep staining (not removable, generalized) |
| Marginal staining | A | | Undetectable margin or slight detectable step (catches explorer going one way) |
| | B | | Detectable crevice (catches explorer going both ways) |
| | | C | Obvious crevice |
| Fracture | A | | None |
| | B | | Small chip |
| | | C | Bulk fracture |
| Postoperative Sensitivity | A | | None |
| | | C | Present |
| Other failures (color change, wear, etc) | A | | None |
| | | C | Present |

years. Longevity of resin composite restorations, which were placed in Nagasaki University Hospital, was retrospectively studied using patient records. Almost all resin composites had been placed following the principle of minimally invasive dentistry established by Fusayama[32]. This study was approved by the Institutional Review Board of Nagasaki University School of Dentistry. Informed consent was obtained to use their records and information for the study.

Survival time was defined as the age when the restoration was replaced, repaired or tooth extracted. If restorations still survived at the end of the study, they were treated as censored cases. Data from the restorations placed between 1982 to1994 in the hospital were not included in this study due to their uncertain recall rates. Data from clinical trials[29-31] and from restorations placed in other dental practices were also excluded from the study. Survival analyses were performed by the Kaplan-Meier method and the log-rank test was used for comparison using a statistical software package (JMP 7, SAS Institute, Cary NC, USA). The Cox proportional hazards (PH) model was used to study the dependence of survival time on potential explanatory variables and controlled for confounding factors (Table 2). Retreatment risk was objectively rated based on a clinical history at the last visit (mainly in 2005) with reference to a previous report[33]: low (no restorations placed during the last 3 years), medium (one or two restorations placed during the last 3 years) and high (three or more restorations placed during the last 3 years). In addition, the retreatment risk was assumed to be constant from the beginning. With respect to restorative materials, mostly Kuraray Medical (Tokyo, Japan) products, such as Clearfil Photo Bond, Liner Bond II and SE Bond in combination with Clearfil AP-X, were used. Adhesive systems were divided into two groups; the adhesive systems developed by 1993 (ER) and after 1993 (SE). The ER group comprised conventional 2-step etch-and-rinse systems without a primer (*i.e.*, the dentin was etched with phosphoric acid, the etchant was washed off and an adhesive applied), such as Clearfil Photo Bond. The SE group consisted mainly of 2-step self-etch systems (*i.e.*, dentin etching and priming were carried out simultaneously with a self-etching primer, dried, and an adhesive applied), such as Clearfil Liner Bond II and SE Bond. In the case of the self-etch adhesive systems, enamel walls were often etched with phosphoric acid prior to a self-etch application, as indicated by the results of our laboratory studies[34,35]. Therefore, the self-etch systems was divided further into two groups for SK; with (Etch) and without (Non-etch) prior enamel etching. Distribution of restorations and patients by operator, class, patient age, retreatment risk and adhesive was analyzed by the Fisher's exact test. For all of the statistical analyses, a significant level was set at $p<0.05$.

Table 2 Variables used for the Cox proportional hazards model

| | |
|---|---|
| Patient factors | Age (at the time of placement)<br>Gender: male and female<br>Retreatment risk*: low, medium and high |
| Operator factor | SK and Other |
| Material factor | Adhesive system: ER and SE<br>Etch and Non-etch for SK |
| Tooth factor | Class: I, II, III and V<br>Tooth type: premolar and molar for Class I & II<br>central incisor, lateral incisor and canine for Class III<br>anterior, premolar and molar for Class V |

*: low; no restoration during the last three years, medium; 1–2 restorations during the last three years, high; ≥3 restorations during the last three years
SK: the principal investigator; Other: the other 23 dentists
ER: adhesive systems developed before 1993, conventional (without a primer) two-step etch-and-rinse systems such as Clearfil Photo Bond
SE: adhesive systems developed after 1993, mainly two-step self-etch systems such as Clearfil Liner Bond II and SE Bond
Etch: enamel was etched with phosphoric acid prior to a self-etch application.
Non-etch: self-etch systems were applied to both enamel and dentin according to manufacturers' instructions.

## RESULTS

Data from 545 resin composite restorations placed by 24 dentists in 97 patients were obtained. Patient and operator characteristics involved in this study are given in Table 3. The distribution of the restorations and failed restorations by operator, adhesive system and cavity type is summarized in Table 4. A great difference in the sample sizes was found between operators (87.2% for SK and 12.8% for the other dentists), but the percentage distribution of the restorations by class was not significantly different, except for Class IV and Other. Class V restorations were most frequently placed, followed by Class III, Class II and Class I. The recall rate of the restorations placed by SK was 90.8%. Three out of 86 failed restorations were replaced during the investigation period.

Distribution of the restorations, failed restorations and patients by operator, class and patient age at placement is listed in Table 5. Although no significant difference in the distribution of the patients by the age at placement was observed between the operator groups, significant differences in the distribution of the restorations by the age were found between operators as well as among cavity types. Approximately 80% of the restorations were placed in patients aged from 40 to 70 years. With respect to the failure rates, there were no significant differences among the ages at placement, regardless of the operator. Only for Class V restorations was a significant difference found between the operators. Class II restorations placed by SK tended to show a lower failure rate than that by the other dentists ($p$=0.070). Among the other dentists, there were no differences between cavity types. For SK, however, significant differences were found between Class I and Class II restorations and between Class I and Class V restorations.

Table 3 Patient and operator characteristics

| | | |
|---|---|---|
| Number of patients | | 97 |
| Male | | 37 |
| Female | | 60 |
| Mean age at the investigation | | 63.4 (11.7) |
| | range | 19.6–86.4 |
| Mean age at the placement | | 57.7 (12.6) |
| | range | 8.8–82.2 |
| Mean DMFT at the investigation | | 19.5 (6.2) |
| Number of operators | | 24 |
| Dept. of Cariology | | 8 |
| Dept. of Periodontics | | 3 |
| Dept. of Fixed Prosthodontics | | 5 |
| Dept. of Removable Prosthodontics | | 3 |
| Other | | 5 |

( ): standard deviation

The distribution of the restorations, failures and patients by operator, adhesive, class and the retreatment risk is shown in Table 6. Approximately 30% of the patients were rated high retreatment risk. There were

Table 4 Distribution of restorations and failed restorations by operator, adhesive system and class

| Class | SK Adhesives ER | SK Adhesives SE Etch | SK Adhesives SE Non-etch | SK Adhesives SE All | SK Subtotal | Other Adhesives ER | Other Adhesives SE | Other Subtotal | Total |
|---|---|---|---|---|---|---|---|---|---|
| Class I | 12 (3) | 13 (4) | 1 (0) | 15 (4) | 27 (7) | 0 | 4 (2) | 4 (2) | 31 (9) |
| Class II | 56 (5) | 37 (3) | 14 (0) | 56 (4) | 112 (9) | 6 (1) | 11 (3) | 17 (4) | 129 (13) |
| Class III | 38 (4) | 42 (12) | 40 (5) | 96 (18) | 134 (22) | 2 (0) | 11 (3) | 13 (3) | 147 (25) |
| Class IV | 6 (1) | 2 (2) | 2 (1) | 4 (3) | 10 (4) | 0 | 0 | 0 | 10 (4) |
| Class V | 6 (1) | 43 (3) | 95 (6) | 154 (14) | 160 (15) | 3 (1) | 33 (9) | 36 (10) | 196 (25) |
| Other | 5 (1) | 13 (3) | 10 (5) | 27 (9) | 32 (10) | 0 | 0 | 0 | 32 (10) |
| Total | 123 (15) | 150 (27) | 162 (17) | 352 (52) | 475 (67) | 11 (2) | 59 (17) | 70 (19) | 545 (86) |

( ): number of failed restorations
Class V includes restorations in non-carious cervical lesions.
Recall rate of resin composite restorations placed by SK was 90.8%.

Table 5 Distribution of restorations, failed restorations and patients by operator, class and patient age at placement

| | Class | < 20 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70 > | Total |
|---|---|---|---|---|---|---|---|---|---|
| SK | I | 0 (0) [0] | 0 (0) [0] | 2 (0) [2] | 10 (3) [8] | 5 (4) [4] | 9 (0) [9] | 1 (0) [1] | 27 (7) [23] |
| | II | 1 (0) [1] | 8 (3) [2] | 13 (1) [6] | 16 (1) [13] | 21 (2) [13] | 41 (1) [22] | 12 (1) [5] | 112 (9) [54] |
| | III | 0 (0) [0] | 2 (0) [1] | 3 (0) [2] | 21 (2) [9] | 23 (3) [14] | 74 (15) [24] | 11 (2) [5] | 134 (22) [48] |
| | V | 0 (0) [0] | 3 (0) [1] | 4 (0) [3] | 14 (3) [8] | 75 (6) [18] | 53 (5) [23] | 11 (1) [5] | 160 (15) [46] |
| | Subtotal | 1 (0) [1] | 13 (3) [2] | 22 (1) [6] | 61 (9) [20] | 124 (15) [26] | 177 (21) [40] | 35 (4) [12] | 433 (53) [88] |
| Other | I | 4 (2) [2] | 0 (0) [0] | 0 (0) [0] | 0 (0) [0] | 0 (0) [0] | 0 (0) [0] | 0 (0) [0] | 4 (2) [2] |
| | II | 4 (0) [1] | 0 (0) [0] | 1 (0) [1] | 2 (1) [2] | 4 (1) [4] | 2 (1) [2] | 4 (1) [2] | 17 (4) [11] |
| | III | 1 (0) [1] | 0 (0) [0] | 2 (0) [2] | 1 (0) [1] | 1 (0) [1] | 5 (3) [4] | 3 (0) [2] | 13 (3) [10] |
| | V | 0 (0) [0] | 0 (0) [0] | 0 (0) [0] | 3 (2) [2] | 15 (1) [5] | 5 (1) [3] | 13 (6) [3] | 36 (10) [12] |
| | Subtotal | 9 (2) [2] | 0 (0) [0] | 3 (0) [2] | 6 (3) [3] | 20 (2) [9] | 12 (5) [6] | 20 (7) [5] | 70 (19) [23] |
| Total | | 10 (2) [1] | 13 (3) [2] | 25 (1) [7] | 67 (12) [21] | 144 (17) [32] | 189 (26) [44] | 55 (11) [14] | 503 (72) [94] |

( ): number of failed restorations, [ ]: number of patients

no significant differences in the distribution of the patients and the restorations by the risk between operators, between cavity types, or between adhesive systems, except for Class III restorations placed by SK with SE. With respect to the failure rates, they increased with the retreatment risk regardless of operators or adhesive systems. In the high retreatment risk patients, 38.2% of the restorations were placed and 63.9% of the failed restorations were replaced. For the restorations placed with SE, there were significant differences in failure rates between the medium and high retreatment risk, independent of operators. However, subgroups consisting of class, adhesive and operator showed no significant effect of the risk levels on the failure rates, except for Class III restorations placed with SE by SK.

Survival rates at 10 years are summarized in Table 7. Ten-year survival rates for SK and the others were 84.2% and 71.8%, respectively. Statistical analyses indicated significant differences in survival between the operator groups (Figure 1). However, there was no significant difference in the survival time of the failed restorations. Median longevity of the failed restorations for SK and the other 23 dentists was 2.9 and 3.1 years, respectively. The variables in the Cox PH model and their statistical significance for the restorations placed by SK are listed in Table 8. The retreatment risk had a great influence on the longevity, especially for Class III and V restorations (Figure 2). However, patient age and gender showed no significant effects. Enamel walls in 47.2% of the restorations were etched with phosphoric acid prior to the self-etch application. There were no significant differences in survival curves between the adhesive groups, except for Class III, in which the Etch group showed a significant lower survival function compared to the ER and Non-etch groups (Figure 3). Although survival time of Class I restorations was

Table 6 Distribution of restorations, failed restorations and patients by operator, adhesive, class and retreatment risk

| | Adhesive | | Class I Risk | | | Class II Risk | | | Class III Risk | | | Class V Risk | | | All Risk | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High | |
| SK | ER | R | 0(0) | 7(1) | 5(2) | 5(0) | 32(2) | 19(3) | 2(0) | 21(1) | 15(3) | 0(0) | 5(1) | 1(0) | 7(0) | 65(5) | 40(8) | 112(13) |
| | | P | 0 | 7 | 5 | 1 | 19 | 12 | 1 | 15 | 11 | 0 | 5 | 1 | 1 | 34 | 18 | 53 |
| | SE | R | 1(0) | 12(4) | 2(0) | 4(0) | 37(3) | 15(1) | 0(0) | 39(3) | 57(15) | 14(0) | 90(5) | 50(9) | 19(0) | 178(15) | 124(25) | 321(40) |
| | | P | 1 | 10 | 2 | 3 | 23 | 11 | 0 | 19 | 16 | 2 | 30 | 15 | 3 | 47 | 22 | 72 |
| | Subtotal | R | 1(0) | 19(5) | 7(2) | 9(0) | 69(5) | 34(4) | 2(0) | 60(4) | 72(18) | 14(0) | 95(6) | 51(9) | 26(0) | 243(20) | 164(33) | 433(53) |
| | | P | 1 | 16 | 6 | 3 | 33 | 18 | 1 | 27 | 19 | 2 | 34 | 16 | 3 | 59 | 26 | 88 |
| Other | ER | R | 0(0) | 0(0) | 0(0) | 0(0) | 6(1) | 0(0) | 0(0) | 2(0) | 0(0) | 0(0) | 1(0) | 2(1) | 0(0) | 9(1) | 2(1) | 11(2) |
| | | P | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 8 | 2 | 10 |
| | SE | R | 0(0) | 2(0) | 2(2) | 0(0) | 7(1) | 4(2) | 0(0) | 8(2) | 3(1) | 3(0) | 13(2) | 17(7) | 3(0) | 30(5) | 26(12) | 59(17) |
| | | P | 0 | 1 | 1 | 0 | 3 | 2 | 0 | 8 | 1 | 1 | 5 | 4 | 1 | 12 | 5 | 18 |
| | Subtotal | R | 0(0) | 2(0) | 2(2) | 0(0) | 13(2) | 4(2) | 0(0) | 10(2) | 3(1) | 3(0) | 14(2) | 19(8) | 3(0) | 39(6) | 28(13) | 70(19) |
| | | P | 0 | 1 | 1 | 0 | 9 | 2 | 0 | 9 | 1 | 1 | 6 | 6 | 1 | 16 | 6 | 23 |
| Total | | R | 1(0) | 21(5) | 9(4) | 9(0) | 82(7) | 38(6) | 2(0) | 70(6) | (19) | 17(0) | 109(8) | 18(17) | 29(0) | 282(26) | 192(46) | 503(72) |
| | | P | 1 | 17 | 7 | 3 | 39 | 19 | 1 | 34 | | 3 | 37 | 18 | 4 | 61 | 29 | 94 |

R: restorations; P: patients; ( ): number of failed restorations

Table 7 10-year survival rates of resin composite restorations (%)

| Class | SK ER | SK SE Etch | SK SE Non-etch | SK SE All | SK Total | Other Total | References SK[2] | Other[2] | Aoyama[7] | Opdam[4] | Opdam[5] | Rodolpho[10] | Smales* [41] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Class I | 62.2$^{a}$ | 44.4$^{**a}$ | — | 48.6$^{**a}$ | 58.4$^{a}$ | 33.3$^{**a}$ | 82.5$^{a}$ | 62.5$^{a}$ | 60.4$^{\#}$ | 82.2$^{\#}$ | | > 90.0 | |
| Class II | 86.8$^{a}$ | 91.1 $^{b}$ | 100$^{**a}$ | 91.8 $^{b}$ | 89.6$^{bc}$ | 73.1 $^{a}$ | 76.8$^{a}$ | 53.3$^{a}$ | | | 88.1** | > 90.0 | |
| Class III | 84.2$^{a}$ | 65.7 $^{a}$ | 82.5 $^{a}$ | 76.9 $^{a}$ | 79.0$^{ab}$ | 76.9 $^{a}$ | 88.3$^{a}$ | 69.1$^{a}$ | | | | | 72.0 |
| Class V | — | 92.5 $^{b}$ | 91.9 $^{a}$ | 88.7 $^{b}$ | 88.4$^{c}$ | 63.1 $^{a}$ | 72.4$^{a}$ | 58.2$^{a}$ | | | | | 69.9## |
| Total | 83.4 | 80.7 | 90.4 | 84.5 | 84.2 | 71.8 | 82.6 | 61.5 | | | | | |

Groups with the same superscript letters in the column are not significantly different at $p<0.05$ estimated by the log-rank test.
Groups connected by vertical line are not significantly different at $p<0.05$ estimated by the Cox proportional hazards model. Variables were age at placement, gender, retreatment risk, adhesive and class.
2: Data of 164 and 182 restorations, which were placed by SK and other 37 dentists between 1982 and 1994, were also obtained during the investigation period[38]. Using these data, 10-year survival rates were estimated as references.
[ ]: reference number
*: many restorations would have been placed without and enamel etching and bonding.
**: survival rate at 9 years
#: survival rate for posterior resin composite restorations
##: anterior teeth only

significantly shorter compared to that of other cavity types, tooth type had no significant influence irrespective of cavity type.

## DISCUSSION

In daily practice, an evidence-based approach is becoming more expected of dentists[1]. Unfortunately, however, well controlled long-term clinical studies of resin composite restorations, especially for anterior teeth, are limited in number. In addition, randomization of patient-, operator-, material- and tooth-related factors is important for generalization of outcomes, but this seems to be very difficult to achieve. Under these circumstances, a retrospective study on clinical performance of resin composite restorations in combination with multivariate analysis may be useful to estimate more valid longevity data in a relatively short time[4]. Recently, four long-term studies with survival analysis of posterior resin composite restorations placed in general practice have been published[4,5,7,10].

In the present study, a total of 433 resin composite restorations placed by SK were statistically analyzed. The clinical performance of these restorations was less influenced by operator factors compared to that of the other 23 dentists. In addition, the follow-up rate of resin composite restorations fulfills the requirement (more than 80%) that is necessary to obtain a high level of evidence. Analysis of such data may make it possible to provide more academic information than that of other dentists' data. On the other hand, the findings obtained from SK, whose specialty is adhesive dentistry, do not seem to reflect the results obtained in general practice. In order to control for operator bias, it is required that many dentists are involved in a study[6]. A total of 70 restorations were placed in 23 patients by 23 dentists. About 40% of the restorations were placed in high retreatment risk patients. Fifteen of 70 restorations were placed by dentists whose clinical experience was 5 years or less. In addition, 51 of 70 restorations were placed by dentists who had no experience of research on adhesive dentistry. As a result, analysis of these data might provide more valid information about the actual longevity of resin composite restorations. Unfortunately, however, the data of the other dentists were not analyzed with the Cox PH model, since when they were divided into several groups the sample sizes became too small.

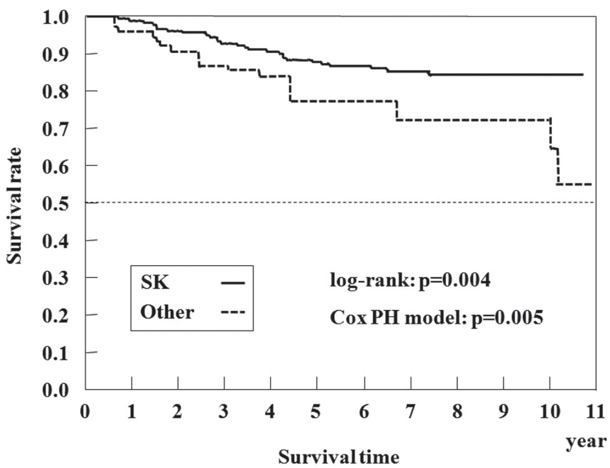


Fig. 1 Survival curves of resin composite restorations by operator.
Survival of resin composite restorations placed by SK ($n$=433) were compared with that by the other 23 dentists ($n$=70). For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity type, adhesive system and operator were included as variables.

It has been assumed that the operator's skill has a great effect on the longevity of restorations, and this appears to be generally accepted. However, few clinical studies have been performed to verify this hypothesis[11]. Ten-year survival rates of resin composite restorations were estimated 84.2% for SK and 71.8% for the other 23 dentists. There was a significant difference between the operator groups, especially for Class II and V restorations, which are likely to require more restorative skills. SK has been engaged in studying resin composite restorations and teaching operative dentistry since graduation in 1981, and thus may have more experience and skills in resin composite restorations compared to most of the other dentists. This probably resulted in enhanced longevity of the resin composite restorations. Another possible explanation is criteria for retreatment. A survival analysis using an insurance claim database revealed that a change of dentist had a significant and negative effect on the longevity of restorations[36]. All failed restorations for SK were replaced by himself, whereas 80% of the failed restorations for the other dentists' group were replaced by colleagues (50% were replaced by SK mainly due to retentive failure of Class V restorations). No standardized diagnostic criteria for replacement of restorations have yet been established. Our previously reported questionnaire study on decision-making for retreatment of restorations[37] revealed a wide variation between operators and/or departments, as also shown by Elderton and Nuttall[38]. Since the start of the

Table 8 Variables in the Cox proportional hazards model and their statistical significance for the restorations placed by SK

| Factors | Variables | Class I | Class II | Class III | Class V | All |
|---|---|---|---|---|---|---|
| Patient factor | Age at placement | 0.725 | 0.110 | 0.084 | 0.801 | 0.901 |
| | Gender | 0.283 | 0.136 | 0.527 | 0.968 | 0.420 |
| | Retreatment risk | 0.877 | 0.304 | 0.025 | 0.036 | < 0.001 |
| Material factor | Adhesive* | 0.518 | 0.522 | 0.016 | 0.670 | 0.316 |
| Cavity factor | Class | — | — | — | — | 0.039 |
| | Tooth type | 0.113 | 0.248 | 0.085 | 0.565 | — |

*: analyzed adhesive groups varied with Class; ER and Etch for Class I, ER, Etch and Non-etch for Class II and III, Etch and Non-etch for Class V, ER and SE for all.

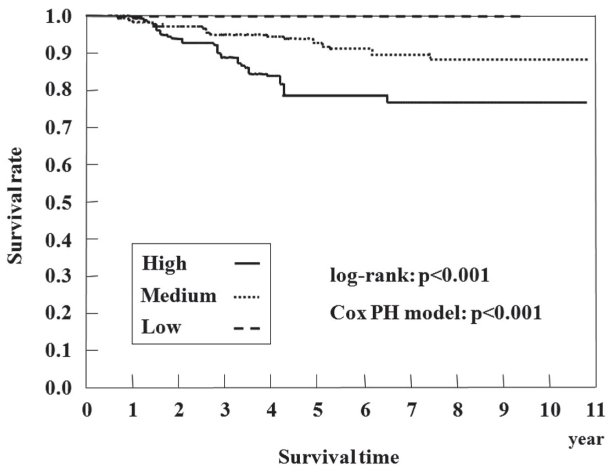


Fig. 2 Survival curves of resin composite restorations by the retreatment risk.
A total of 433 Class I, II, III, and V resin composite restorations, which were placed in 88 patients by SK, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity type and adhesive system were included as variables.

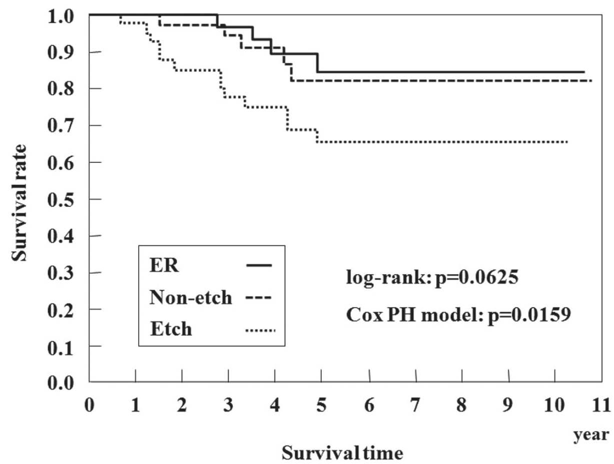


Fig. 3 Survival curves of Class III resin composite restorations by the adhesive group.
A total of 120 Class III resin composite restorations, which were placed with 2-step self-etch systems (Non-etch: $n$=40, Etch: $n$=42) or conventional 2-step etch-and-rinse (ER: $n$=38) by SK, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, tooth type and adhesive group were included as variables.

maintenance system in 1995, SK has changed criteria for replacement to avoid a repeat restoration cycle[38]. First choice is monitoring a defective restoration as recommended by Gordan *et al.*[39]. This may give a proper decision on treatment of the defective restoration and extend its longevity. Data from 164 and 182 restorations, which were placed by SK and other 37 dentists respectively between 1982 and 1994, were also obtained during the investigation period[40]. Ten-year survival rates obtained from these data support the results of the present study (Table 7). Smales and Hawthorne[41] reported that 10-year survival rates of Class III and Class V resin composites, which were placed by 20 dentists in three long-established, large, busy private general dental practices, were 72.0% and 69.9%, respectively. Aoyama *et al.*[7] reported that 10-year survival rate of 60.4% of posterior resin composite restorations placed by dentists in a general practice in Japan. These survival rates seem to be comparable to those obtained from the other dentists' groups.

The age of failed restorations has also been presumed to be a valid indicator of actual clinical performance[42]. In the present study, there was no significant difference in the survival time of the failed restorations between the operator groups. In addition, the median longevity of the failed restorations was markedly shorter than that estimated by the survival analysis as speculated in other cross-sectional studies[22,23]. This is probably because failed restorations do not always show similar age distributions to those of acceptable restorations. Various findings associated with the occurrence of failures were found in long-term clinical studies. Rodolpho *et al.*[10] demonstrated steep declines in survival rates after 10 years. Opdam *et al.*[5] reported that few failures occurred before 4 years of clinical service. Lindberg *et al.*[26] indicated that the failures occurred about linearly over the whole follow-up of 9 years. Three 10-year clinical studies[17,25,43] and the present study showed that more than half of the failed restorations were replaced within 5 years.The median age of failed restorations as a criterion for restoration performance may require more careful interpretation.

Patient-related factors are also likely to have a great effect on the longevity of restorations[5,7,9,11,23,42]. Caries susceptibility of younger (<18 years) or older (>65 years) patients is considered to be higher than at other life stages[44]. Hawthorne and Smales[9] indicated that lower survival rates occurred when the restorations were placed in the less than 20-year and over 60-year age groups compared to 21–40-year and 41–60-year age groups. Mean patient age at restoration placement in the present study was 54 years, and approximately 70% of the restorations were placed in patients aged from 40 to 65 years. Only a few percent of the restorations were placed in patients whose age was less than 20 years. In addition, 74% of the patients had attended regularly for 5 to 11 years. Although professional tooth cleaning and/or topical application of fluoride were not routinely carried out at each recall visit, caries risk of regular attenders might have been improved by patient education. Therefore, neither patient age nor gender may affect the survival rates of the restorations. These findings are supported by other studies.[4,5,7]

Opdam *et al.*[5] reported that high risk for caries significantly increased the failure rate of posterior resin composite restorations. Aoyama *et al.*[7] indicated that the longevity of restorations placed in posterior teeth was associated with the occlusal status, that is, the longevity was significantly shorter in patients with Eichner Indices B1, B2 and B3 compared to those with Index A[45]. In the present study, the retreatment risk was determined based on the number of restorations during the previous 3 years (2002–2005). As expected from this definition, the Cox PH model indicated that the retreatment risk had the greatest influence on the longevity of resin composite restorations.

Many studies reported that the SE adhesives showed significantly higher dentin bond strengths compared to the ER adhesives[3]. However, our study[46] raised the concerns about the long-term marginal integrity at the enamel margins restored with a 2-step self-etch adhesive. Therefore, enamel walls were often etched with phosphoric acid prior to the self-etch application, since laboratory studies[34,35] suggested a significant improvement of marginal sealing by beforehand enamel etching. A relatively thick (more than 100 µm) adhesive layer is required for 2-step self-etch systems to obtain high bond strength. This seems to be another clinical disadvantage, especially for Class II. Because of these characteristics associated with the self-etch adhesives and good clinical performance of Photo Bond[43,47], SK has still used this ER adhesive for Class I, II and III restorations. There were no objective indications for the use of each adhesive group but the application of the SE adhesives to NCCLs.

Beyond our expectation, there were no significant differences in survival functions between the adhesive groups, except for Class III. Van Dijken *et al.*[15,16] have evaluated many adhesive systems using the same protocol, and reported that such adhesive systems had a great influence on the longevity of resin composite in NCCLs, retention of which mainly depends on effective bonding to dentin. In addition, they revealed a wide variation of dentin bonding effectiveness between the systems, independent of adhesive category. These findings are supported by the results of a systematic review[48]. In our practice, products from Kuraray Medical, which showed good clinical performance in many studies,[4,5,14,15,18,19,29,43,48,49] have been used. On the other hand, no significant effects of adhesive systems on survival function of Class I and II restorations were found in previous studies[4,10,17,18]. This is probably because resin composites show high and stable bonding to enamel etched with phosphoric acid, regardless of adhesive system. Recently, however, Perdigão *et al.*[50] reported that all-in-one adhesives showed significantly poorer marginal adaptation in posterior restorations compared to an etch-and-rinse system, and one of the self-etch systems resulted in unacceptable clinical performance after 2 years. Concerning Class III restorations, few data on the effect of adhesive systems on the long-term clinical performance are available. An explanation for the significant difference found in Class III may be that a high risk patient had 7 out of 12 replacements in the Etch group. Regarding the prior enamel etching, Peumans *et al.*[49] also reported no significant effect on the longevity of the restorations in NCCLs. A comparison between the ER and the SE groups in Class V restorations was impossible to make due to a great difference in sample sizes.

With respect to the distribution of resin composite restorations by class, Class V restorations were the most, followed by Class III and Class II restorations. There was a greater percentage of Class V restorations in the present study compared to previous studies[9,23] in which Class II restorations were the most frequently placed. This is probably due to the relatively higher patient age compared to the previous studies[9,23]. Restorations in NCCLs increased with patient age as reported by Tyas[24]. Recent university-centered clinical studies with a similar patient age distribution performed in Japan showed the same ranking order[19,43].

Concerning the effect of cavity type on longevity, Class I restorations tended to show significantly poorer survival compared to other cavity types. The reason for this is not clear. Rodolpho *et al.*[10] reported that Class I restorations showed a significantly better survival function than Class II restorations. Lundin and Koch[13] found no significant difference between cavity types. Nikaido *et al.*[43] indicated that though the sample sizes were small, Class II restorations tended to show better survival than Class I restorations. Opdam *et al.*[5] revealed a significant effect of the amount of restored surface on the survival. The 10-year survival rate of Class II restorations placed by SK (89.6%) seems to be comparable to that of other similar clinical studies[4,5,10] in which the restorations were placed by one or two skillful dentists in general practice. Survival rates obtained from long-term clinical trials of Class II resin composite restorations ranged from 72.7% to 93.3%[12,14,18,26]. For Class III restorations, there are a few long-term clinical studies with a sample size of more than 30[27,28,41]. Although these studies were published before 1997, 10-year survival rates ranged between 72% and 89%, and seem to be equivalent to those of the present study (79.0%). For Class V restorations, recently several long-term RCTs have been published[15,16,20,21,49]. Survival rates from these studies showed a wide range of between 5.3% and 100%. It should be noted that the RCTs were performed using NCCLs in order to evaluate the effectiveness of adhesive systems, and secondary caries was infrequently detected. The failure mode of such restorations in NCCLs may be different from that in carious lesions at the gingival third of the buccal or lingual surfaces. Cross-sectional studies, which may include restorations in both cervical carious and non-carious lesions, indicated that secondary caries and marginal discoloration were the main reasons for replacement[22,24]. In the present study, most of the Class V restorations placed by SK were for NCCLs. The survival rate of these Class V restorations seems to be comparable to that of a clinical trial[49] in which almost the same adhesive system and restorative technique were used.

In the present study, no significant effect of tooth type on survival was found, regardless of cavity type. For Class I and Class II restorations, there are inconsistent findings[5,7,10,12-14]. If a significant effect was found, restorations placed in premolars always showed significantly better survival rates compared to those in molars[5,10,12,14]. This may be due to the greater occlusal forces on molar restorations compared to premolar restorations. Another possible explanation is poorer access to the operating field for molars, and such teeth may require more extensive restorations. For Class V restorations, although an earlier study[8] indicated a significant effect of tooth location and characteristics on retention, many recent studies[20,21,30,31,48] reported similar findings to ours. Little information about the relationship between tooth type and clinical performance of Class III restorations is available. In this study, a valid application of the Cox PH model demands that all data are independent. In a clinical study on operative dentistry, a few or several restorations are generally placed in one patient. In order to solve this problem, a bootstrap procedure was performed in one study[4], but no measures were taken in the present study. In addition, the retreatment risk was assumed to be constant from the time the restorations were placed, despite its variability. Further study is required to provide more valid information about the longevity of resin composite restorations.

## CONCLUSIONS

Within the limits of the present study, it can be concluded that at least 60% of resin composites placed in adults are likely to survive 10 years, irrespective of cavity type. In addition, patient, operator, material and cavity factors may have an interactive influence on the longevity of resin composite restorations. Particularly, the retreatment risk may have a great impact on the survival.

## ACKNOWLEDGMENTS

This study was supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (16591918 and 20592230). The authors wish to thank Prof. Martin Tyas, University of Melbourne, for assistance in preparation of the manuscript.

## REFERENCES

1) Chadwick B, Treasure E, Dummer P, Dunstan F, Gilmour A, Jones R, Phillips C, Stevens J, Rees J, Richmond S. Challenges with studies investigating longevity of dental restorations —a critique of a systematic review. J Dent 2001; 29: 155-161.
2) Manhart J, Chen HY, Hamm, Hickel R. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. Oper Dent 2004; 29: 481-508.
3) Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, Van Landuyt K, Lambrechts P, Vanherle G. Adhesion to enamel and dentin: current status and future challenges. Oper Dent 2003; 28: 215-235.
4) Opdam NJM, Bronkhorst EM, Rooters JM, Loomans BAC. A retrospective clinical study on longevity of posterior composite and amalgam restorations. Dent Mater 2007; 23: 2-8.
5) Opdam NJM, Bronkhorst EM, Rooters JM, Loomans BAC. Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. J Adhes Dent 2007; 9: 469-475.
6) Mjör IA. The reasons for replacement and the age of failed restorations in general dental practice. Acta Odontol Scand 1997; 55: 58-63.
7) Aoyama T, Aida J, Takehara J, Morita M. Factors associated with the longevity of restorations in posterior teeth. J Dent Hlth 2008; 58: 16-24.
8) Heymann HO, Sturdevant JR, Bayne S, Wilder AD, Sluder TB & Brunson WD. Examining tooth flexure effects on cervical restorations: A two-year clinical study. J Am Dent Assoc 1991; 122: 41-47.
9) Hawthorne WS, Smales RJ. Factors influencing long-term restoration survival in three private dental practices in Adelaide. Aust Dent J 1997; 42: 59-63.
10) da Rosa Rodolpho PA, Cenci MS, Donassollo TA, Loguércio AD, Demarco FF. A clinical evaluation of posterior composite restorations: 17-year findings. J Dent 2006; 34: 427-435.
11) Nicolaisen S, von der Fehr FR, Lunder N, Thomsen I. Performance of tunnel restorations at 3-6 years. J Dent 2000; 28: 383-387.
12) Van Dijken JWV. Direct resin composite inlays/onlays: an 11 year follow-up. J Dent 2000; 28: 299-306.
13) Lundin SA, Koch G. Class I and II posterior composite resin restorations after 5 and 10 years. Swed Dent J 1999; 23: 165-171.
14) Pallesen U, Qvist V. Composite resin fillings and inlays. An 11-year evaluation. Clin Oral Invest 2003; 7: 71-79.
15) Van Dijken JWV, Sunnegårdh-Grönberg K, Lindberg A. Clinical long-term retention of etch-and-rinse and self-etch adhesive systems in non-carious cervical lesions. A 13 years evaluation. Dent Mater 2007; 23: 1101-1107.
16) Van Dijken JWV, Pallesen U. Long-term dentin retention of etch-and-rinse and self-etch adhesives and a resin-modifies glass ionomer cement in non-carious cervical lesions. Dent Mater 2008; 24: 915-922.
17) Fukushima M, Nakamata T, Tsukuda Y, Yuda J, Okamoto A, Iwaku M. Longevity of chemically-cured posterior composite restorations –10-year clinical observation–. Jpn J Conserv Dent 1993; 36: 331-340.
18) Mair LH. Ten-year clinical assessment of three posterior resin composites and two amalgams. Quintessence Int 1998; 29: 483-490.
19) Akimoto N, Takamizu M, Momoi Y. 10-year clinical evaluation of a self-etching adhesive system. Oper Dent 2007; 32: 3-10.
20) Ritter AV, Swift EJ Jr, Heymann HO, Sturdevant JR, Wilder AD Jr. An eight-year clinical evaluation of filled and unfilled one-bottle dental adhesives. J Am Dent Assoc 2009; 140: 28-37.
21) Wilder AD Jr, Swift EJ Jr, Heymann HO, Ritter AV, Sturdevant JR, Bayne SC. A 12-year clinical evaluation of a three-step dentin adhesive in noncarious cervical lesions. J Am Dent Assoc 2009; 140: 526-535.
22) Browning WD, Dennison JB. A Survey of failure modes in composite resin restorations. Oper Dent 1996; 21: 160-166.
23) Burke FJT, Wilson HNF, Cheung SW, Mjör IA. Influence of patient factors on age of restorations at failure and reasons for their placement and replacement. J Dent 2001; 29: 317-324.
24) Tyas MJ. Placement and replacement of restorations by selected practitioners. Aust Dent J 2005; 50: 81-89.

25) Gaengler P, Hoyer I, Montag R. Clinical evaluation of posterior composite restorations: The 10-year report. J Adhes Dent 2001; 3: 185-194.
26) Lindberg A, van Dijken JW, Lindberg M. Nine-year evaluation of a polyacid-modified resin composite/resin composite open sandwich technique in Class II cavities. J Dent 2007; 35: 124-129.
27) Qvist V, Strøm C. 11-year assessment of Class-III resin restorations completed with two restorative procedures. Acta Odontol Scand 1993; 51: 253-262.
28) Jokstad A, Mjör IA, Nilner K, Kaping S. Clinical performance of three anterior restorative materials over 10 years. Quintessence Int 1994; 25: 101-108.
29) Kubo S, Yokota H, Kawasaki K, Hayashi Y. Five-year clinical evaluation of two adhesive systems in non-carious cervical lesions. J Dent 2006; 34: 97-105.
30) Kubo S, Yokota H, Yokota H, Hayashi Y. Two-year clinical evaluation of one-step self-etch systems in non-carious cervical lesions. J Dent 2009; 37: 149-155.
31) Kubo S, Yokota H, Yokota H, Hayashi Y. Three-year clinical evaluation of a flowable and a hybrid resin composite in non-carious cervical lesions. J Dent 2010; 38: 191-200.
32) Fusayama T. A simple pain-free adhesive restorative system by minimal reduction and total etching. Ishiyaku Euro America Inc, St. Louis; 1993.
33) Caries diagnosis and risk assessment. A review of preventive strategies and management. J Am Dent Assoc 1995; 126: 1S-24S.
34) Kubo S, Konishi Y, Yokota H, Watanabe T, Ohsawa M. Effect of enamel etching with phosphoric acid on marginal sealing of current adhesive systems. J Dent Res 1996; 75 special issue: Abstr. No. 3015, 394.
35) Sata Y, Kubo S, Yokota H, Watanabe T, Hayashi Y. Effect of enamel etching with phosphoric acid on marginal sealing of cervical resin composite restorations. Jpn J Conserv Dent 1999; 42: 909-918.
36) Bogacki RE, Hunt RJ, del Aguila M, Smith WR. Survival analysis of posterior restorations using an insurance claims database. Oper Dent 2002; 27: 488-492.
37) Kubo S, Yokota H, Hayashi Y. Decision-making of retreatment of restorations. 2007 Nov 8, 9; Okayama, Japan. Jpn J Conserv Dent 2007; 50 (autumn special issues): 102.
38) Elderton RJ, Nuttall NM. Variation among dentists in planning treatment. Br Dent J 1983; 154: 201-206.
39) Gordan VV, Garvan CW, Blaser PK, Mondragon E, Mjör IA. A long-term evaluation of alternative treatment to replacement of resin-based composite restorations. Results of a seven-year study. J Am Dent Assoc 2009; 140: 1476-1484.
40) Kubo S. Clinical bonding durability of resin composite restorations. Adhesive Dentistry Symposium; 2009 Feb 21, 22; Sendai, Japan. Adhes Dent 2008; 26: 174.
41) Smales RJ, Hawthorne WS. Long-term survival and cost-effectiveness of five dental restorative materials used in various classes of cavity preparations. Int Dent J 1996; 46: 126-130.
42) Mjör IA, Dahl JE, Moorhead JE. Age of restorations at replacement in permanent teeth in general dental practice. Acta Odontol Scand 2000; 58: 97-101.
43) Nikaido T, Takada T, Kitasako Y, Ogata M, Shimada Y, Yoshikawa T, Nakajima M, Otsuki M, Tagami J, Burrow MF. Retrospective study of the 10-year clinical performance of direct resin composite restorations placed with the acid-etch technique. Quintessence Int 2007; 38: 240-246.
44) Sturdevant CM, Roberson TM, Heymann HO, Sturdevant JR editors. The art and science of Operative Dentistry. 3rd ed. St Louis; 1995. p.179-180.
45) Eichner K. Über eine gruppeneinteilung des lückengebisses für die prothetik. DZZ 1955; 10: 1831-1834.
46) Kubo S, Yokota H, Watanabe T, Ohsawa M, Matsumoto H. Adhesive properties of Liner Bond II (KB-110) system. Part 1 Relationship between marginal seal and tensile bond strength. Jpn J Conserv Dent 1994; 37: 1216-1223.
47) Kubo S, Nakasa R, Hayashi Y. Survival analysis of resin composite and cast restorations. Jpn J Conserv Dent 2001; 44: 802-809.
48) Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: A systematic review of current clinical trials. Dent Mater 2005; 21: 864-881.
49) Peumans M, De Munck J, Van Landuyt K, Poitevin A, Lambrechts P, Van Meerbeek B. Eight-year clinical effectiveness of a two-step self-etching adhesive with and without selective enamel etching. Dent Mater 2010; 26: 1176-1184.
50) Perdigão J, Dutra-Corrêa M, Anauate-Netto C, Castilhos N, Carmo ARP, Lewgoy HR, Amore R, Cordeiro HJD. Two-year clinical evaluation of self-etching adhesives in posterior restorations. J Adhes Dent 2009; 11; 149-159.