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Review article

Longevity of resin composite restorations

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Summary In daily practice, an evidence-based approach is becoming more expected of dentist. However, only outcomes obtained from clinical studies are accepted as evidence. Although many clinical trials have been performed, most of them are short-term studies, whereas long-term studies are likely to provide more reliable evidence. In this article, prospective studies and retrospective longitudinal clinical studies on resin composite restorations were systematically searched with PubMed for literature in English and with Japana Centra Revuo Medicina (Ichushi Web) for articles in Japanese. Finally, 21 long-term (8 years or more) prospective studies and nine retrospective studies with survival analysis were selected and reviewed from more than 561 papers. The overall findings suggest that at least 60% of resin composite restorations will last more than 10 years when proper materials are applied correctly. Patient-, operator-, material- and tooth-related factors may have an influence on the survival of resin composite restorations. Appropriate maintenance policies based on MI concepts are claimed to enhance the longevity of resin composite restorations.

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1. Introduction

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. However, laboratory studies do not always reflect the clinical behavior of the material because of the differences between laboratory and clinical conditions [3]. Therefore, Evidence-based Medicine accepts outcomes obtained from clinical studies only as evidence.

If many long-term randomized controlled trials of resin composite restorations had been performed, a high level of evidence for their longevity would be available [1,2,4]. At present, longevity of restorations is estimated by three kinds of clinical study: a prospective study [5—25]; a retrospective longitudinal study with censored cases [26—33]; and a retrospective cross-sectional study on failed restorations only (without censored cases) [34—39]. Although the prospective studies can provide more reliable evaluation than the retrospective studies, prospective clinical trials are limited in number since they 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 unavailable. In addition, the prospective studies may not reflect the real-life of restorations in general dental practice or daily living since they include many biases such as operator- and patient-related factors [1,7,29,30,35]. This is supported by the fact that secondary caries rarely occurred in the prospective cohort studies [5,9,12—14,19,21—25] though it is the principal reason for failure of restorations in daily general practice [29—39]. Retrospective studies are less defined than prospective ones, however, certain advantages of the retrospective studies are that many restorations can be examined in a relatively short time and more clinicians and patients are involved [30,35]. This may compensate for possible flaws and failures due to the method of data acquisition. Therefore, Mjör et al. [35—37] retrospectively investigated the longevity of failed restorations with an attempt to reflect a real-life situation. The lack of censored cases in such studies may mitigate against an accurate estimate the longevity of restorations. Survival analysis can deal with censored cases 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 survival analysis can evaluate the effect of two or more metric and/or nonmetric variables on survival.

The purpose of this article is to provide a review of long-term (8 years or more) prospective and retrospective studies with censored cases of resin composite restorations, and to investigate factors contributing to their longevity.

2. Search methods for identification of studies and their results

2.1. Electronic searches

Systematic searches were carried out with PubMed for literature in English and with Japana Centra Revuo Medicina (Ichushi Web) for literature in Japanese on January 1 in 2010. The searches covered the 20-year period of 1990—2009. Search strategies are given in Tables 1—3.

2.2. Searching references of the selected articles

A search of references in the selected articles for other eligible articles was made.

2.3. Inclusion criteria

The inclusion criteria were longitudinal studies on clinical performance of resin composite restorations placed in permanent teeth over 8 years or more. Studies presented at academic meetings, the full texts of which had not yet been published in any journals, were also included. Selection was done by the author alone.

Table 1 Search strategy for prospective longitudinal studies on resin composite restorations in PubMed.

#1 composite resin
#2 dentin-bonding agents
#3 #1 or #2
#4 dentistry, operative
#5 longitudinal studies
#6 follow-up studies
#7 prospective studies
#8 #5 or #6 or #7
#9 #3 and #4 and #8
#10 crowns
#11 dental abutments
#12 dentures
#13 dental porcelain
#14 pit and fissure sealants/therapeutic use
#15 tooth, deciduous
#16 tooth, nonvital
#17 root canal filling materials/therapeutic use
#18 tooth fractures/therapy
#19 #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19
#20 #9 not #19
21 ("1990"[Publication Date]: "2009" [Publication Date]) Limits: Humans Sort by: Publication Date

Table 2 Search strategy for retrospective studies with survival analysis on resin composite restorations in PubMed.

#1 composite resins
#2 dentistry, operative
#3 retrospective studies
#4 survival analysis
#5 #1 and #2 and #3 and #4
#6 ("1990"[Publication Date]: "2009" [Publication Date]) Limits: Humans Sort by: Publication Date

Table 3 Search strategy for longevity of resin composite restorations in JCRM.

#1 composite resins
#2 survival rate
#3 longevity
#4 long-term follow up
#5 clinical evaluation
#6 #1 and #2
#7 #1 and #3
#8 #1 and #4
#9 #1 and #5
#10 #6 or #7 or #8 or #9
#11 primary tooth
#12 #10 not #11

JCRM: Japana Centra Revuo Medicina (Ichushi Web).

2.4. Results

Four hundred and three prospective studies and 26 retrospective studies in English for potential inclusion in the review were retrieved from the PubMed electronic search. With respect to the 132 articles retrieved from Ichushi Web, if the articles were published as original articles in academic journals, their abstracts were available. After reading all titles and/or abstracts, and applying the inclusion criteria, 21 prospective studies [5—25] and six retrospective studies remained for review [26—31]. Two retrospective studies presented at academic meetings were also included [32,33]. In addition, one 10-year retrospective study with a small sample size, the survival rates of which were calculated by descriptive statistics, was included as it was performed in Japan [40].

3. Prospective studies

Survival rates of resin composite restorations obtained from the long-term prospective studies using the descriptive statistics, potential factors in longevity, such as patient, operator, materials, cavity factors, etc., and main reasons for replacement are summarized in Table 4. More than 10-year (10 and 17 years) survival rates of Class I restorations ranged from 69.4% to 100% in 3 clinical trials [8,18,19], however, it must be noted that the 100% was obtained from the very small sample size ($n = 4$). Around 10-years (4.8—17 years) survival rates of Class II restorations ranged from 58.3% to 100% in 9 clinical trials [8,10,12,15,17—21]. Survival rates of combined Class I and II restorations calculated from four studies varied from 40% to 86.3% [11,13,14,16]. With respect to the survival rate of Class III restorations, five studies provided the rates ranged between 73% and 100% [6—9,19]. No information about Class IV restorations was available. A large number of clinical trials of resin composite restorations in non-carious cervical lesions (Class V) have been performed. However, long-term data from well-designed studies have not been published until recently. Survival rates of Class V restorations obtained from six studies showed a wide range of between 5.3% and 100% [8,19,22—25]. Depending on restorative materials and patient's characteristics, overall findings indicate 10-year survival rates of 70% or more, regardless of cavity type.

4. Retrospective studies

Four out of 6 studies were published in the last 3 years [29—31,40]. Although our retrospective study [28] was published in 2001, there were several possible shortcomings. Therefore, we have been improving the previous study design in order to provide more reliable and informative data [32,33].

Ten-year survival rates of resin composite restorations estimated by survival analysis of the data obtained from the retrospective studies are given in Table 5. Potential factors in longevity, such as patient, operator, materials, cavity factors, etc., and main reasons for replacement are also tabulated. Ten-year survival rates of Class I restorations ranged between 59.9% and 67.8% [32,33,40]. Ten-year survival rates of Class II restorations varied from 55.1% to 89.7% [30,32,33,40]. Survival rates of Class I and II restorations ranged from 60.4% to 83.0% [28,29,31]. The lowest values were obtained from the restorations placed by inexperienced operators or general practitioners [31,33]. With respect to Class III, IV and V resin composite restorations, only one study

Table 4 Survival rates of resin composite restorations obtained from long-term prospective studies using the descriptive statistics (%).

1st author, year [Ref.]	Setting, country	Study type	No. of patients	Patient mean age and/or range	No. of operators	No. of restorations at baseline	Materials	Criteria for evaluation	Length of follow up	Recall rates	Class	Survival rates	Main reasons for replacement	Significant factors
Wilder, 2009 [25]	University, USA	RCT	53	—	6	EE: 50 TE: 50 All: 100	OptiBond Dual Cure; Herculite XRV	Modified USPHS	12	EE: 54 TE: 38 All: 46	V NCCLs	EE: 93 TE: 84 All: 89	Retention failure, no caries	None (patient, operator, lesion characteri-stics)
Ritter, 2009 [24]	University, USA	RCT	33	53 27—77	7	OS: 48 PB: 51 All: 99	OptiBond Solo (OS), Prime & Bond 2.1 (PB); Prodigy for OS, TPH Spectrum for PB	Modified USPHS	8	OS: 60 PB: 53	V NCCLs	OS: 70.8 PB: 68.6	Retention failure, no caries	None (adhesives, patient and lesion characteri-stics)
Van Dijken, 2008 [23]	—	RCT	88	56.7 28—83	1	41—47 for respective system All: 270	Opti Bond, Permagen, Scotchbond Multi-purpose, Syntac classic, PSA, Vitremer	Modified USPHS	13	79.6	V NCCLs	13.2—64.4	Retention failure, no caries	Adhesive systems
Van Dijken, 2007 [22]	University, Sweden	RCT	119	54.5 24—83	1	43—57 for respective system All: 337	Clearfil Liner Bond, All Bond 2, ART Bond, PUB 3, Gluma 2000, Denthesive;	Modified USPHS	13	81.6	V NCCLs	5.3—73.7	Retention failure, no caries	Adhesive systems
Gordan, 2007 [21]	University, USA	PLS	31	34 21—62	2	I: 26 II: 35 Total: 51	FL-Bond; Beautifil	Modified USPHS	8	67	I ⟨16⟩ II ⟨25⟩	100	Poor marginal integrity but clinically acceptable	None
Lindberg, 2007 [20]	PDC, Sweden	RCT	57	34.6 17—68	2	75 for each group All: 150	Prime Bond 2.1; Prisma TPH, open sandwich (SW: Dyract base)	Modified USPHS	9	90.0	II	All: 90.7[a]	8/14: caries 3/14: fracture	None (restorative techniques)
Akimoto, 2007 [19]	University, Japan	PLS	42	—	2	87	Clearfil Liner Bond II; 4 resin composites	Modified USPHS	10	51	I ⟨4⟩ II ⟨2⟩ III ⟨17⟩ V ⟨19⟩	100	Marginal discoloration but clinically acceptable	None
Rodolpho, 2006 [18]	1 GDP, Brazil	CCT	38	42.5[b] (6.4)	1	I: 75 II: 207 Total: 282	Scotchbond 2 & P-50, Prime/XR Bond & Herculite XR	Modified USPHS	17	—	I at 10 years I at 17 years II at 10 years II at 17 years	96[a] 55[a] 92[a] 20[a]	53/98: fracture of resin 16/98: tooth fracture 22/98: caries	Tooth type, cavity type, cavity size

Pallesen, 2003 [17]	University, Denmark	RCT	28	35 19–64	1	BD: 28 EP: 28 All: 56	Gluma Prep 2 and Clearfil New Bond; Brilliant Dentin (BD), Estilux Posterior (EP)	Modified USPHS	11	96	II	BD: 86 EP: 74 All: 84	4/11: fracture of resin 1/11: new caries 2/11: secondary caries	Tooth type
Gaengler, 2001 [16]	University, Germany	PLS	73	18–52	4	I: 115 II: 79 All: 194	Ketac-Bond lining, Universalbond; Visio-Molar radiopaque	CMP index	10	32	I & II	74.2	5/16: secondary caries 3/16: fracture of resin 8/16: loss	None
Van Dijken, 2000 [15]	University, Sweden	CCT	40	48 27–70	1	34	GC lining base, enamel bonding agent; Fulfil	Modified USPHS	11	97	II	72.7	3/9: secondary caries 4/9: fracture of resin 2/9: wear	Tooth type
Lundin, 1999 [14]	University, Sweden	CCT	65 dental students	27 15–45	2	I: 45 II: 92 All: 137	Experimental resin composites (one is Occlusin)	USPHS	10	85.4	I & II	79	No secondary caries	Materials
Raskin, 1999 [13]	University, Belgium	PLS	36 dental students	22.7 19–40	1	I: 42 II: 58 All: 100	Dycal lining, enamel bonding agent; Occlusin	Modified USPHS	10	69	I & II	40–50	10/23: occlusal wear 7/23: proximal wear 4/23: sensitivity 2/23: caries	None
Mair, 1998 [12]	University, England	CCT	Dental students	–	1	30 for each composite All: 90	Cement base, each adhesive, Occlusin, Clearfil Posterior, P-30	–	10	67	II	93.3	No caries (0/4)	Materials
Collins, 1998 [11]	PDC, Australia	CCT	72	16.8[c] 13–32	1	More than 80 for each group All: 330	Cement lining; P-30 (P3), Herculite XR (HX), Heliomolar (HM), Dispersalloy	Modified Michigan & USPHS	8	64.5	I & II	HM: 83.6 HX: 84.6 P3: 90.7 All: 86.3	8/25: secondary caries 8/25: bulk fracture	Materials
Nordbø, 1998 [10]	PDC, Norway	CCT	37	13–17	7	FF: 34 OC: 17 All: 51	Enamel bonding; Fulfil (FF), Occlusin (OC)	USPHS	4.8–9.6	100	II	FF: 59 OC: 88 All: 70	8/16: caries 4/16: poor adaptation	Materials
Millar, 1997 [9]	University, England	PLS	24	43 16–70	3	III: 25 V: 16 All: 44	Dycal lining, enamel bonding resin; Opalux	USPHS	8	56.8	III & V	73[a]	One case was secondary caries but the rest was unclear	None
Shimizu, 1995 [8]	University, Japan	CCT	20	10–40	–	91	Experimental adhesive; Lite-Fil P	Modified USPHS	10	100	I ⟨49⟩ II ⟨12⟩ III ⟨9⟩ V ⟨19⟩	69.4 58.3 77.8 94.7	8/23: secondary caries 8/23: new caries 4/23: extraction	None

Table 4 (*Continued*)

1st author, year [Ref.]	Setting, country	Study type	No. of patients	Patient mean age and/or range	No. of operators	No. of restorations at baseline	Materials	Criteria for evaluation	Length of follow up	Recall rates	Class	Survival rates	Main reasons for replacement	Significant factors
Jokstad, 1994 [7]	GDP, Sweden	CCT	57	40 9–72	1	S ⟨66⟩ C ⟨28⟩ SC ⟨37⟩ All: 131	Dycal, enamel-etch only, Concise (C), Silar (S), Silicap (SC)	USPHS	10	73.3	III: 112 IV: 6 V: 13	S: 77[a] C: 96[a]	Not clear, but secondary caries and fracture seem to be main reasons	Materials
Qvist, 1993 [6]	University, Denmark	RCT	35	41 24–65	1	52 for each procedure All: 104	Dycal lining, Cosmic Bond; Silar	Original	11	86.5	III	A: 78 B: 82 All: 84[a]	5/15: secondary caries 3/15: fracture 2/15: bulk discoloration	None (restorative techniques)
Fukushima, 1993 [5]	University, Japan	CCT	Dental students	–	–	BP: 46 CP: 46 P10: 52 All: 144	Each adhesive; Bellfirm P (BP), Clearfil posterior (CP), P-10 (P10)	–	10	81	I & II	BP: 78 CP: 73 P10: 64 All: 71	11/34: pulpitis 8/34: fracture 5/34: new caries 1/34: secondary caries	None (materials)

[ ]: reference number, PDC: public dental clinic (service), RCT: randomized controlled clinical trial, CCT: controlled clinical trial, PLS: prospective longitudinal study, –: no information, NCCLs: non-carious cervical lesions, EE: etched only the enamel, TE: etched both enamel and dentin, ⟨ ⟩: number of restorations at final recall

[a] Survival rates were estimated by the Kaplan–Meier method, life table analysis, or reading survival curves.

[b] Age at the last examination (SD).

[c] Mean age of 46 patients who attended the 8-year recall, at baseline.

Table 5 Ten-year survival rates of resin composite restorations obtained from retrospective survival analysis (%).

1st author (year) [Ref.]	Setting country	Placement period	No. of patients	Patient age mean (SD) and/or range	No. of operators	No. of restorations	Materials	Criteria[a]	Class	Survival rates	Main reasons for replacement	Significant factors
Aoyama (2008) [31]	1 GDP Japan	1991–2005	95	33.3 (14.2)[b]	Unknown but many	245	–	–	I & II	60.4	68/87: secondary caries	Occlusal status
Opdam (2007) [30]	1 GDP Netherlands	1988–1997	248	18–80	2	TE: 376 SW: 82 Total: 458	RMGI lining cement and Clearfil Photo Bond, Liner Bond 1 combined with PA	–	II	TE: 88.1[c] SW: 70.5[c]	TE: 26/43 caries; SW: 11/34 caries, 18/34 fracture	Lining and caries risk
Opdam (2007) [29]	1 GDP Netherlands	1990–1997	621	–	2	1955	Clearfil Liner Bond 1 combined with PA	–	I & II	82.2	98/259: caries 37/259: fracture 28/259: endodontics	Amount of restored surfaces
Kubo (2001) [28]	University Japan	1982–2000	93	45.4 15–77	1[d]	I: 27 II: 43 III: 219 IV: 17 V: 217 Total: 577	Kuraray products such as New Bond, Photo Bond, Liner Bond II, SE Bond Photo; FII, Photo A, Posterior, AP-X	Modified USPHS	I & II All	83.0 81.2	50/76: unknown, 9/76: pulpitis, 8/76: loss	Cavity type, adhesive system
Smales (1996) [26]	3 GDPs Australia	–1992	100	29.5 (14.6)	20	III: 284 IV: 57 V: 96	–	–	III IV V	72.0 56.3 69.9	Not clear	None (materials)
Nikaido[e] (2007) [40]	University Japan	1992	26	60.4[b] 31–79	9	I: 5 II: 6 III: 10 IV: 5 V: 32 Total: 58	Clearfil Photo Bond, Liner Bond System	Original criteria	I II III IV V All	60.0 66.7 80.0 0.0 75.0 All: 67.2	11/16: not clear, 2/16: pulpitis, 1/16: fracture, 1/16: discoloration	Cavity type
Kubo (2008) [33]	University Japan	1982–2005	55	50.5 (15.3) 7–77	49[f]	I: 28 II: 43 III: 70 V: 116 Total: 257	Conventional 2-step total-etch (Clearfil New Bond, Photo Bond) and 2-step self-etch (Clearfil Liner Bond II, SE Bond) systems	Modified USPHS	I II III V	59.9 55.1 69.7 61.9	Class I: caries Class II: caries and fracture Class III: caries Class V: loss and caries	Risk of retreatment

Table 5 (*Continued*)

1st author (year) [Ref.]	Setting country	Placement period	No. of patients	Patient age mean (SD) and/or range	No. of operators	No. of restorations	Materials	Criteria[a]	Class	Survival rates	Main reasons for replacement	Significant factors
		1995–2005	18	53.7 (21.4) 7–77	24[g]	I–III: 28 V: 38 Total: 66	2-Step self-etch systems (Clearfil Liner Bond II, SE Bond)	Modified USPHS	I–III V	61.1 72.3	33/102: caries 24/102: fracture 16/102: loss 13/102: endodontics Class I: fracture Class II: fracture and caries Class III: caries Class V: loss	Risk of retreatment, cavity type
		1995–2005[h]	101	55.7 (12.8) 15–82	1	I: 33 II: 128 III: 138 V: 180 Total: 479	Conventional 2-step total-etch (Clearfil Photo Bond) and 2-step self-etch (Clearfil Liner Bond II, SE Bond) systems	Modified USPHS	I II III V	60.1 89.7 79.6 89.3		
Kubo (2006) [32]	University Japan	1982–2005	123	54.4 (14.5) 10–82	50[d]	I: 61 II: 193 III: 284 V_1: 82 V_2: 428 Total: 1106	Conventional 2-step total-etch (Clearfil Photo Bond) and 2-step self-etch (Clearfil Liner Bond II, SE Bond) systems	Modified USPHS	I II III V_1 V_2	67.8 73.1 78.8 56.4 87.3[i]	83/243: caries 45/243: loss 33/243: fracture	Adhesive systems

GDP: general dental practice, –: no information, TE: total-etch, SW: sandwich, RMGI: resin-modified glass-ionomer (Vitrebond or GC lining), PA: phosphoric acid etching, V_1: Class V restored with conventional 2-step total-etch systems, V_2: Class V restored with 2-step self-etch systems.

[a] Criteria were not for replaced or retreated restorations but for examination at the last visit.
[b] Age at the investigation.
[c] Survival rate at 9 years.
[d] Most of the restorations were placed by one operator (author).
[e] Survival rates were calculated by descriptive statistics.
[f] 43% of the restorations were placed by dentists with less experience ($\leq$5 years). 71% were placed by dentists without experience of studying adhesion of restorative materials.
[g] 26% of the restorations were placed by dentists with less experience ($\leq$5 years). 65% were placed by dentists at other departments (Prosthodontics, Periodontics, Pedodontics, etc.).
[h] Recall rate of the restorations placed by the author was 91% at the final examination.
[i] Survival rate was estimated without 225 restorations which were involved in clinical trials.

[26] was published and it reported that 10-year survival rates were 72.0% for Class III, 56.3% for Class IV and 69.9% for Class V. In this study 2 circumstances should be noted. One is that many resin composite restorations back in old days would have been placed without enamel etching and bonding, and the other is that the patients attended regularly for check-ups and treatments for 25 years on average. According to our two studies [32,33], 10-year survival rates of Class III and V restorations ranged from 69.7% to 79.6% and from 56.4% to 89.3%, respectively. Nikaido et al. [40] retrospectively investigated the 10-year clinical performance of resin composite restoration placed with the acid etch technique in similar clinical circumstances to our studies, e.g., chair time, cavity preparation, restorative materials and patient characteristics. The results of their study seem to be comparable to ours.

5. Failure modes in resin composite restorations

For Class I and II restorations, caries was the dominant failure reason in four articles [8,10,20,31], restoration fracture exceeded 50% in one paper [18], and caries and fracture were the main reasons for failure in 6 studies [11,15–17,29,33]. Opdam et al. [30] reported an interesting result that the dominant reason changed with restorative techniques; fracture for the cervical lining 'sandwich' technique, and caries for a total-etch technique. For Class III restorations, secondary caries was the main reason for failure in two studies [6,33], but one paper indicated the very low incidence of secondary caries [9]. For Class V restorations, secondary caries was hardly detected in the selected studies [8,9,19,22–25] except one study [33]. It should be noted that many clinical trials of resin composite restorations in non-carious cervical lesions have been performed in order to evaluate the effectiveness of adhesive systems. The failure mode of such restorations in non-carious cervical lesions may be different from those in carious lesions at the gingival third of the buccal or lingual surfaces. Cross-sectional studies, which may include restorations in both cervical caries and non-carious lesions, indicated that secondary caries and marginal discoloration were the main reasons for replacement [34,36,38]. These findings suggest that minimal intervention (MI) concepts [41], such as management of caries risk and monitoring clinical problems, enhance the longevity of restorations.

In our study [33], although 10-year survival rate of resin composite was estimated at 84.9% by the Kaplan–Meier statistic, the median longevity of the failed restorations was 2.8 years. With respect to posterior resin composite restorations, Gaengler et al. [16] discriminated the early failures (e.g., fracture and loss of filling material) from the

Table 6 The effect of patient, operator, materials and tooth factors on the longevity of resin composite restorations.

Factor	Not significant	Tendency	Significant
Patient			
Gender	*Opdam* [29,30], *Aoyama* [31], *Kubo* [32]		
Age	*Opdam* [29,30], *Aoyama* [31], *Kubo* [32,33]		*Hawthorne* [27]
Risk: Caries and/or occlusion		Nordbø [10]	*Opdam* [30], *Aoyama* [31], *Kubo* [33]
Operator			
Experience	*Opdam* [29], *Kubo* [32]		*Hawthorne* [27], *Opdam* [30]
Skill			*Kubo* [32,33]
Specialty	*Kubo* [32]		
Change of operator			*Hawthorne* [27]
Materials			
Adhesive	Mair [12], Ritter [24]		Dijken [22,23]
Resin composite	Collins [11] [a], Mair [12] [a], Pallesen [17], Rodolpho [18], *Opdam* [29]	Nordbø [10]	Lundin [14]
Technique	Qvist [6], Lindberg [20], Wilder [25]		*Opdam* [30]
Tooth			
Class	Raskin [13], Lundin [14], *Kubo* [32]	Millar [9] [b], *Nikaido* [40] [b]	Rodolpho [18], *Kubo* [33]
Surfaces, size	Raskin [13], Lundin [14]		Rodolpho [18], *Opdam* [29,30]
Lesion characteristics	Wilder [25]		
Tooth type	Nordbø [10], Raskin [13], *Aoyama* [31]		Dijken [15], Pallesen [17], Rodolpho [18], *Opdam* [30]

Italic letters express a retrospective study.

[a] No difference in survival rates between materials was found, but significant differences in clinical performance, such as marginal adaptation, marginal discoloration and wear resistance, were observed.

[b] Significant lower survival rates of Class IV compared to other classes, but sample sizes were very small.

late failures (e.g., approximal secondary caries), which is supported by other studies [33,37]. Opdam et al. [30] reported that most of the failures did not occur before 4 years of clinical service. Rodolpho et al. [18] demonstrated steep declines in survival curves after 10 years. For Class V restorations, Ritter et al. [24] reported substantial deterioration of clinical performance between 3-year and 8-year evaluations. Van Dijken et al. in their 13-year clinical studies [22,23] observed various degradation patterns of the resin—dentin bond associated with adhesive systems. These findings indicate the necessity and importance of long-term clinical studies.

6. Contributing factors

It has been considered that the longevity of dental restorations is dependent upon many different factors including patient-, operator, materials- and tooth-related factors [2,6,34,37]. The effect of these factors on the longevity of resin composite restorations examined in the selected literatures and our studies [5—33,40] are summarized in Table 6.

6.1. Patient-related factors

6.1.1. Gender and age at placement

In the selected articles for the present review, no effects of gender or age on the survival rates were consistently found [29—32], except for one study [27]. It should be noted that the number of children, whose caries risk may be higher than other life stage (generation) [37], was very small in these articles [29—32]. Hawthorne and Smales [27] indicated that lower survival rates occurred when the restorations were placed in the 0—20-year and over 60-year age groups compared to 21—40-year and 41—60-year age groups. These findings may be related to higher rates of secondary caries, tooth fractures and root caries in the relevant groups.

6.1.2. Caries risk and occlusion

Opdam et al. [30] reported that a Cox regression analysis revealed a significant increase in the failure rate of the posterior resin composite restorations for high caries risk patients. Aoyama et al. [31] 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. In our study [33], retreatment risk was objectively rated based on a clinical history referring to a previous report [42]: low (no restorations in the last 3 years), medium (one or two restorations in last 3 years) and high (three or more restorations in last 3 years). In addition, the retreatment risk was assumed to be constant from the beginning. There were significant differences in survival curves between high risk and others as shown in Fig. 1.

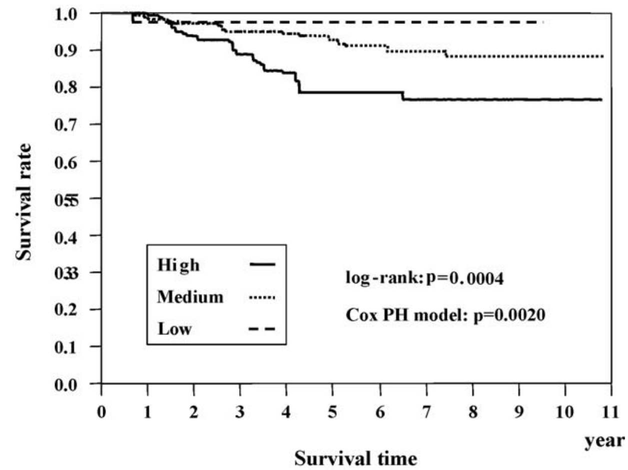

Figure 1 Survival curves of resin composite restorations by retreatment risk. A total of 479 Class I, II, III, and V resin composite restorations, which were placed by the author between 1995 and 2005, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity design and adhesive system were included as covariates.

6.2. Operator-related factors

6.2.1. Experience (years since graduation)

Experience may have an influence on skill and criteria for replacement [36,37,39]. The influence of experience on the longevity of resin composite restorations was studied in three selected articles and our study [27,29,30,32]. No consistent results were found even in similar studies [29,30]. The influence of experience varied between restorative techniques. These are probably because of the small numbers of operators. Another possible factor is the year while the operators in their dental schools since the material and technology in restorative dentistry have considerably changed during recent years.

6.2.2. Skill and specialty

It has been speculated that the operator's skill has a great effect on the longevity of restorations, and there seems to be no disagreement about this speculation. However, few clinical studies have been performed to verify this hypothesis [43]. In our study [33], there was a significant difference in 10-year survival rates between the author and the other 24 dentists (Fig. 2). However, Cox proportional hazards model indicated no significant effects of experience or specialty (research fields and departments) on the survival function among 24 dentists.

6.2.3. Criteria for replacement

Criteria for replacement may have some effect on the longevity of resin composite restorations [9,29], as suggested by Browning and Dennison [34]. Unfortunately, standardized diagnostic criteria for replacement of restorations have not established yet. Although it is relatively easy to obtain agreement from each operator in the case of pulpitis, retention failure and fracture of restorations, it is more difficult to obtain agreement on secondary caries, marginal discoloration, moderate color mismatching, and composite wear [1,40]. Hawthorne and Smales [27] indicated that a change of dentist had no significant effect on restoration survival except for except resin composite restorations in which the change tended to show a positive effect. On the other hand, a survival analysis using an insurance claim database revealed that a change of dentist had a significant and negative effect

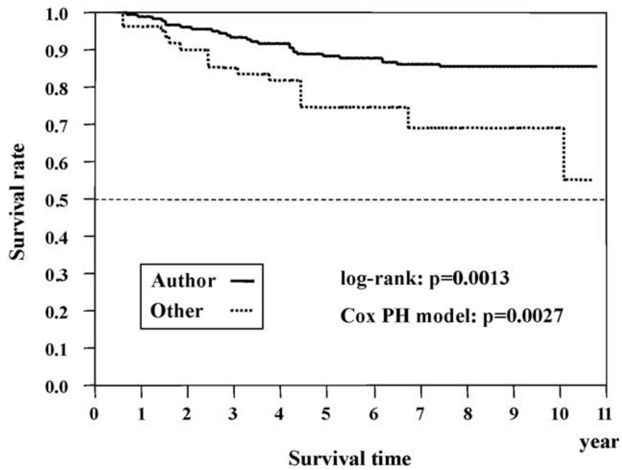

Figure 2 Survival curves of resin composite restorations by operator. A total of 416 Class I, II, III, and V resin composite restorations were placed with two-step self-etch systems by the author (n = 352) and the other 20 dentists (n = 64) between 1995 and 2005. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity design and operator were included as covariates.

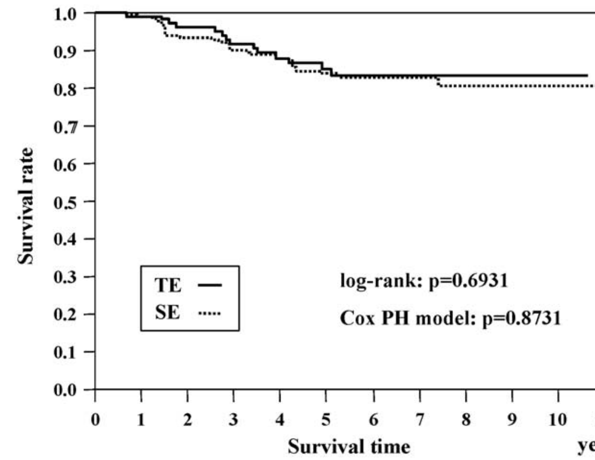

Figure 3 Survival curves of resin composite restorations by adhesive system. A total of 299 Class I, II and III resin composite restorations, which were placed two-step self-etch systems (SE; n = 179) and conventional total-etch-and-rinse (TE; n = 120) by the author between 1995 and 2005, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity design and adhesive system were included as covariates.

on the longevity of restorations [44]. Modified or original United States Public Health Service (USPHS) criteria were used in 17 out of 21 prospective studies [7—11,13—15,17—25]. Chadwick et al. [1] discussed the problems associated with outcome measures of restoration failures. In addition, USPHS criteria are not widely used in daily practice even at university hospitals, and not among general practitioners (at least in Japan), since evidence and consensus are still searched for the criteria for replacement. Deterioration of marginal integrity increased with time, but most restorations were evaluated still clinically acceptable [19,21,24,25]. There is an urgent need for development of reliable and more objective criteria for replacement of restorations based on evidence and MI concepts.

6.3. Material-related factors

6.3.1. Adhesive systems

Van Dijken et al. [22,23] have consecutively evaluated many adhesive systems using the same protocol, and reported that adhesive systems had a great influence on retention of resin composite in non-carious cervical lesions. 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 [4]. In the rest of the selected articles, however, no significant effects of adhesive systems on survival function were found. This is probably because resin composites show high and stable bonding to enamel etched with phosphoric acid, regardless of adhesive system. Another possible explanation is that only one or a few adhesives systems were used in the studies. Generally, products from Kuraray Medical, such as Clearfil Photo Bond, Liner Bond II and SE Bond, showed good clinical performances in many studies [4,5,12,17,19,22,28—30,32,33,40]. Our study [33] revealed that no significant difference in survival function between 2-step self-etch (mainly Clearfil Liner Bond II and SE Bond) and conventional total-etch-and-rinse (Clearfil Photo Bond) systems up to 10 years (Fig. 3).

6.3.2. Resin composite

For resin composites the influential factors on the survival are considered, fracture toughness, wear resistance, color stability and surface texture. Five articles demonstrated that the posterior resin composites used did not show significant differences in their survival rates [11,12,17,18,29]. However, two of these five studies reported significant effects of resin composites on clinical performance, such as marginal adaptation, marginal discoloration and wear resistance, within the clinically acceptable range [11,12]. Nordbø et al. [10] showed a possible effect of restorative materials on the longevity of Class II restorations. Lundin and Koch [14] indicated a significant difference in failure rates from 5 to 10 years between two experimental resin composites developed by the same manufacturer. The only difference in these two resin composites was the addition of barium aluminum silicate to make one of them radiopaque.

6.3.3. Restorative technique

Lindberg et al. [20] indicated no significant differences in 9-year survival rates of Class II restorations between hybrid resin composite restorations and open sandwich restorations, in which a polyacid-modified resin composite was placed as first layer in the cervical part of the cavity and following layers were placed with a resin composite. By contrast, Opdam et al. [30] reported that a total-etch technique showed a significantly higher 9-year survival rate of Class II restorations compared to a closed-sandwich technique in which a thin layer of resin-modified glass-ionomer lining cement was applied on the entire dentin surface. Wilder et al. [25] revealed that the 12-year clinical performance of a dual-cured adhesive was excellent and was not affected by dentin acid etching. Qvist and Strøm [6] reported no significant difference in survival rates of Class III restorations at 11

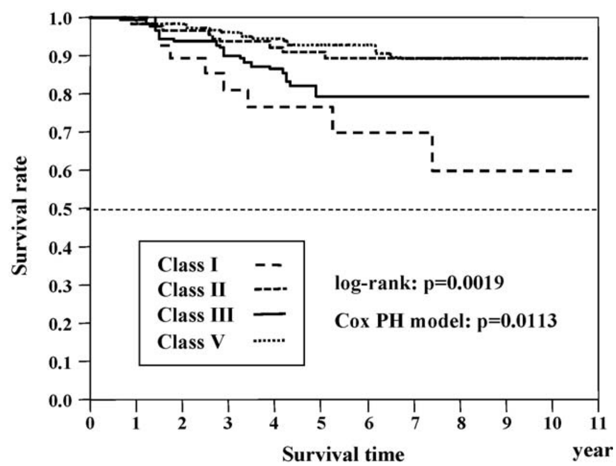

Figure 4 Survival curves of resin composite restorations by class. A total of 479 Class I (33), II (128), III (138), and V (180) resin composite restorations, which were placed by the author between 1995 and 2005, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity design and adhesive system were included as covariates.

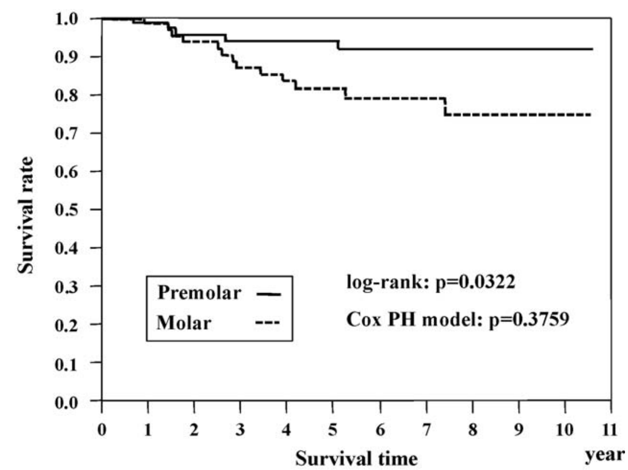

Figure 5 Survival curves of resin composite restorations by tooth type. A total of 161 Class I and II resin composite restorations, which were placed in premolars (84) and molars (77) by the author between 1995 and 2005, were analyzed. For the Cox proportional hazards model, gender, age at placement, retreatment risk, cavity design, adhesive system and tooth type were included as covariates.

years between restorative techniques, mainly with or without an enamel bevel.

6.4. Tooth (cavity)-related factors

6.4.1. Class and cavity size (the amount of restored surfaces)

With respect to the comparison between Class I and Class II restorations, there are inconsistent findings [13,14,18,32,33,40]. In addition, there are contradictory outcomes even in the articles, which demonstrated significant differences between cavity designs. Rodolpho et al. [18] reported that Class I resin composite restorations showed significant better survival function compared to Class II restorations, whereas Kubo et al. [33] indicated opposite results. In our earlier study [32], there were no significant differences in the longevity between Class I, II, III and V restorations. In the later study [33], however, significant differences were found between classes (Fig. 4). Although the sample sizes of Class I restorations in both studies were markedly smaller compared to those of other classes, the later study may provide more reliable information since the relatively high recall rate of 91% was obtained. Concerning the effect of cavity size, there are also inconsistent findings [13,14,18,29,30]. All three articles [18,29,30], which showed significant effects on longevity demonstrated that failure rates significantly increased with the number of the restored surfaces.

6.4.2. Tooth type (premolars vs molars)

Although three articles showed no significant effect of tooth type on the longevity of posterior resin composite restorations [10,13,31], four articles demonstrated that restorations placed in premolars showed significant better survival rates compared to those in molars [15,17,18,30]. This may be due to the greater occlusal forces on molar restorations compared to premolar restorations. Another possible explanation is poorer access to operating field in molars, and which may require more extensive restorations. Fig. 5 shows survival curves of resin composite restorations by tooth type obtained from our data. The log-rank test indicated significant difference between premolars and molars, while the Cox proportional hazards model revealed no significant difference between them. Cox proportional hazards model allows analyzing the effect of several risk factors on survival and is useful to control for confounders due to multivariate analysis. Therefore, the results obtained from Cox proportional hazards model seems to be more reliable.

7. Conclusions

From the overall findings, it can be concluded that at least 60% of resin composite restorations would survive more than 10 years when proper materials are applied correctly. In addition, appropriate maintenance policies based on MI concepts are able to increase the longevity of resin composite restorations, and may result in the enhancement of general health of the patients.

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