Review Article

Longevity of occlusally-stressed restorations in posterior primary teeth

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Abstract: ***Purpose***: To compile a survey of the longevity and reasons for failure of stainless steel crowns, amalgam, glass-ionomer, composite and compomer restorations in stress-bearing cavities of primary molars. ***Methods***: This work reviewed the dental literature of 1971 up to July 2003 for longitudinal, controlled clinical studies and retrospective cross-sectional studies. Only studies investigating the clinical performance of restorations in primary teeth with an observation period of at least 2 years were included. Annual failure rates of stainless steel crowns, amalgam, glass-ionomer, composite and compomer restorations were determined and failure reasons were discussed. Results: Annual failure rates in stress-bearing cavities of primary molars were determined to be: 0-14% for stainless steel crowns, 0-35.3% for amalgam restorations, 0-25.8% for glass-ionomer restorations, 2-29.1% for atraumatic restorative treatments, 0-15% for composite restorations, and 0-11 for compomer restorations. Main reasons for failure were secondary caries, marginal deficiencies, fracture, and wear. (*Am J Dent* 2005;18:198-211).

Clinical significance: Stainless steel crowns are still a valid restorative procedure for heavily destroyed primary molars; however, especially in smaller cavities, the adhesive technique with compomers and composites can be successfully used in a great number of cases.

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Introduction

Alterations in dental restorative treatment patterns combined with the introduction of new and improved restorative materials and techniques affect the longevity of dental restorations.[1] Marked changes in the use of restorative materials have occurred during the past 10 to 20 years.[2,3] Alleged adverse health effects and environmental concerns due to the release of mercury gave rise to controversial discussions about the use of amalgam as a contemporary restorative material.[3,4] Alternatives to amalgam restorations in restoring carious lesions in the primary dentition include stainless steel crowns, glass-ionomers and derivates, composites and compomers.

This review analyzed the literature for the longevity of restorations in Class I and II cavities of primary posterior teeth. Only clinical studies with at least 2 years duration were considered for this survey.

Materials and Methods

Literature review

A MEDLINE literature search covering the time from 1971 to July 2003 was performed for clinical studies covering occlusally-loaded restorations in primary molars. The keywords used were: primary molar, deciduous molar, clinical, *in vivo*, longevity, amalgam, glass-ionomer cement, glass polyalkenoate cement, hybrid ionomer cement, compomer, composite, preformed metal crowns, and stainless steel crowns. Articles from relevant references cited in this literature were also retrieved. The articles were analyzed for the criteria listed in Tables 1-7. Only peer-reviewed studies published in English or German and with an observation period of restorations at risk of at least 2 years were considered. The evidence level of the studies was analyzed according to the classification in Table 1.

Table 1. Classification of evidence level (modified according to AHCPR 1992) for clinical studies.

Level	Levels of evidence for rating clinical studies
A	Evidence from meta-analysis of randomized controlled trials Evidence from at least one randomized controlled trial
B1	Evidence from at least one controlled study without randomization Evidence from at least one other type of quasi-experimental study
B2	Evidence from descriptive studies, such as comparative studies, correlation studies, and case-controlled studies
C	Evidence from expert committee reports or opinions, consensus conferences and / or clinical experience of respected authorities, or both

Results

The literature search produced 149 articles, 57 of which fulfilled the selection criteria (Table 2-7). Since recent studies have indicated that clinical trials lasting only 1-year are questionable to demonstrate any difference in clinical performance of the materials under observation, only investigations with 2-year data or longer were reviewed. Furthermore, all publications that failed to provide adequate success rates or failure rates were excluded from further evaluation. If articles were identified that reported the results of the same clinical investigation at different recall times, only the publication with the most recent data was included in this review.

Preformed metal crowns (stainless steel crowns)

Since their introduction, preformed metal crowns (PMC), also known as stainless steel crowns (SSC) and nickel chrome crowns, have been an important part of treatment strategies for restoring posterior primary teeth. Several modifications by the manufacturers improved the anatomical shape and made them more suitable to use.

Literature reviews[5-7] showed that the use of preformed metal crowns was recommended in the presence of large carious lesions that include multiple surfaces of the affected teeth. In cases of high caries risk incidence, crowned teeth showed benefits due to their full coverage. The indication given in the literature for use of PMCs for primary molars also includes their use for restoration after pulp therapy, as abutments for space maintainers and in the occurrence of developmental defects, fractures and extensive wear.

For permanent molars, PMCs are recommended as an interim restoration in very specific situations as for teeth with developmental defects, for those within the erupting process and sometimes due to financial considerations.[5,7] Their easy and quick application contributes to a clear savings in treatment time, which becomes more apparent when the focus is directed at the need of subsequent treatment for crowned teeth compared to that for filled teeth.[8,9]

The results of clinical studies covering SSCs in primary molars are summarized in Table 2. Of these, three studies compared the durability of restorations for children with early childhood caries treated under general anesthesia.[10-12] One of these also included a comparison with conscious sedation.[12] Three further investigations of the 13 articles reported the success rate of pulpotomies restored with PMCs in comparison to their restoration with other materials.[13-15] All except three of the studies were retrospective evaluations of patient records.[8,13,16]

The earliest study was by Braff[9] in 1975, comparing stainless steel crowns with multisurface amalgam restorations over a mean follow-up of 30 months. A total of 76 crowns in 39 patients placed at a mean patient age of 4.2 years were evaluated. The amalgam restorations to be included in this study were selected from the same group of patients. A total of 150 multisurface amalgam restorations in 35 patients were available. Control and PMC restorations were placed in the same patients. Four patients were treated only with PMCs (6 PMCs). The author however decided to include all the available crowns. Any number of replacements or repairs of old surfaces were accepted. All data used, were taken from the patient charts and it was not possible to determine the reason for re-restoring a tooth. The amalgam restorations consisted of two or more surfaces, corresponding to a mean of 2.4 surfaces. Failures due to pulp inflammation were excluded to avoid false failures. The failure rate of the amalgam group was 86% with 131 failures, compared to a failure rate of 25% with 19 failures in the crown group. Without replacements, these values were 88.7% and 30.3% respectively, which is rather high compared with other amalgam studies as listed below.

Dawson *et al*[17] reported results from a retrospective study comparing amalgam restorations (one-surface: 114, two-surface: 102) and stainless steel crowns (64) in 114 patients over a period of at least 2 years. The SSCs showed a survival rate of 87.5%. Failures due to pulp inflammation were excluded in this investigation too. The survival rates of the one-surface amalgam restorations (63.2%) were more than double as high as that of the two-surface amalgam restorations (29.4%). The authors[17] concluded that before the permanent molar erupts into the occlusion (before the age of 8) SSC was the treatment of choice, particularly for multisurface lesions in the primary first molar.

Eriksson *et al*[8] evaluated 104 crown/control tooth pairs in 77 patients, 6-7 years old at the time of crowning in a prospective, nonrandomized clinical investigation. At the time of the initial treatment, the extension of decay in the teeth to be crowned was equal to or worse than that of the control teeth.

Table 2. Longevity of stainless steel crowns in primary molars (SSC = stainless steel crown, GA = general anesthesia, LA = local anesthesia, SD = study design, SM = split mouth, R = randomized, CO = controlled, C = cross-sectional, RD = rubber dam, CR = cotton rolls).

Year of publication	First author	Years	Black class	Restorative materials	Restorations at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anesthesia	SD	Mode of isolation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
1975	Braff [9]	2.5	II	SSC	76	39	Mean 4.2; range 3-11		C		75	10		B2	
1981	Dawson *et al*[17]	2	II	SSC	64		Mean 5.5		C		87.5	6.25	Recementation	B2	Treatment by postgraduate students
1988	Messer & Levering[21]	9	II	SSC	331	131			C		88	1.3		B2	Age effect of failure rate. With increasing age at placement less failures.
1988	Eriksson *et al*[8]	3	II	SSC	104	77	Range 6-7		CO		58	14	Recementation	B1	
1990	Wong & Day[18]	5	II	SSC	18				C		100	0		B2	
1990	Roberts & Sheriff[16]	5	II	SSC	673	468		LA	CO	RD	92	1.6	Cement failures, crown defects	B1	One operator
1991	O'Sullivan & Curzon[10]	2	II	SSC	210	80		GA	C	RD	97	1.5		B2	Treatment by postgraduate students
1994	Papathanasiou *et al*[19]	5	II	SSC	183	128	Range 3-10	LA	C	RD	68	6.4		B2	Teeth with pulpotomy included
1996	Einwag & Dunninger[20]	8	II	SSC	66	66			C		83	2.1	Fractures, caries	B2	
1997	Gruythuysen & Weerheijm[13]	2	II	SSC	67	57	Mean 5.5	LA	CO	RD	85	7.5		B1	All teeth with pulpotomy
2000	Farooq *et al*[14]	2-7	II	SSC (FP) SSC (IPT)	78 55	88	Mean age 5.4		C		82 93	9 3.5		B2	Comparison of teeth treated with formocresol pulpotomy (FP) or indirect pulp therapy (IPT)
2002	Holan *et al*[15]	2.4	II	SSC	287	227	Mean age 6		C		87	5.4		B1	All teeth with pulpotomy

This led to amalgam restorations of one, two or three surfaces and restorations that covered four or more surfaces of the tooth. Only 80 of the control teeth received amalgam restorations. The remaining 24 teeth did not need any treatment. Subsequent treatment was required for 21% of the crowned teeth and for 64% of the control teeth. Failures due to pulp inflammations were not excluded. The failure rates after 2 years were 13% for the group of PMCs and 26% for the control group. After 5 years, the findings were 71% and 75% respectively. These values included replacement of the control restorations and recementation of the PMCs.

Roberts & Sherriff[16] carried out a 10-year prospective evaluation of 1024 amalgam restorations and 673 PMCs in primary molar teeth. The amalgam restorations consisted of two, or less than two surfaces. The true failure rate was calculated. Failures due to pulpal involvement were excluded. Two percent of the PMCs, 4% of the one- and 11.6% of the two-surface amalgam restorations failed. The authors compared in the same study permanent molar PMCs with control restorations. The failure rates were 2% for the PMCs and 11% for the amalgam restorations. A 5-year estimated survival rate was given for the restorations of the primary dentition. This amounted to 73.3% and 66.6% for one- and two-surface amalgam restorations, respectively, and 92% for PMCs. The 5-year survival rate for the first primary molars treated with amalgam was 65.7% and 71.5% of the second primary molars.

Wong & Day[18] reported data from a retrospective analysis carried out using an independent sampling technique meaning that one patient received one restoration. Of the 361 patients treated (up to 6 years old), 110 received Class I amalgam restorations and 233 Class II amalgam restorations. The other 18 patients were treated with PMCs. The survival rate after a mean follow up of 5 years was 59.6% for the Class I and 46.7% for the Class II amalgam restorations. The PCMs showed no failure. There was weak evidence that the life span depended on the caries susceptibility of the patient, and good evidence that it depended on the age of the patients at the time of treatment.

Papathanasiou *et al*[19] reported retrospective data that were selected by use of multistage, stratified, random sampling technique. The collected data consisted of 128 patients with 604 teeth treated with SSCs (183), amalgam (198), composite (173), glass-ionomer (GI) restorations (173), evaluated over a period of 2 years. The dmft was medium (4-7) or high (>7) for 91% of the treated children. More than 50% of the treated teeth belonged to 3-5 year-old children. The median survival time (MST) was 32 months for composite and 12 months for GI. The 5-year survival estimate values were approximately 68% for SSCs and 60% for amalgam restorations. The 4-year survival estimate of the GI restorations was only 5% when almost 40% of the composite, 60% of the amalgam, and 68% of the SSC restorations survived. The failures due to pulpal inflammation were not considered.

Einwag & Dünninger[20] examined two alternative methods of restoring primary teeth that had multisurface lesions in a clinical retrospective study of 132 patients over 8 years. Each patient received one SSC and a two-surface amalgam restoration. The survival rate of SSCs was 92% after 3 years, 90% after 4.5 years and 83% after 8 years. The amalgam restorations showed lower survival rates after 3 and 4.5 years, 66% and 36% respectively. The authors concluded that the procedure of placing SSCs was relatively simple compared to the problems that might be encountered when multisurface amalgam restorations were placed in primary molars. Thus, SSCs offered, in their opinion, a distinctly more acceptable alternative for both the patient and the dentist.

Messer & Levering[21] reported an overall 88% success rate for SSCs. Crowns placed over formocresol pulpotomies showed a greater relative risk (3.97 times) of failure than those placed over vital coronal pulps. The success rate showed an increase with increasing initial age of treatment. These findings were compared to a success rate of 73% for all amalgam restorations (Class I and II) placed at an average patient age of 5 years.[22] Crowns placed in the younger age group (4 years) showed a failure rate approximately half that of the Class II amalgam restorations, for each year up to 10 years of service.[21]

Despite the above investigations where the patients were treated under normal conditions, there are three further studies[10-12] which fulfilled the selection criteria of the literature search and are about the durability of restorations performed on children with behavior problems and extensive caries lesions, treated under general anesthesia. O'Sullivan & Curzon[10] retrospectively evaluated 80 patients with a mean age of 4.6 years at the time of treatment under general anesthesia over a 2-year period. Fifty percent of the treated patients were between 3-5 years of age. The restorations of the 445 teeth were all carried out under rubber dam: 102 of the teeth received two-surface amalgam restorations, four received one-surface amalgam restorations, 113 teeth received a composite or a glass-ionomer restoration, 210 SSCs and 16 strip crowns. The failure rates were 16% for amalgams, 29% for composites and glass-ionomer restorations, 3% for SSCs and 0% for the low evaluated number of strip crowns. Of the restored 445 teeth, 143 vital pulpotomies were performed. The authors[10] reported a failure rate of 2.0% for the pulpotomized teeth but did not make clear which the true and false failure rates were, because they did not report the restorations of these teeth. The authors recommended the placement of SSCs for treatment of young children with extensive carious lesions in primary molars under general anesthesia.

The comparison of restorations for children with early childhood caries under general anesthesia or conscious sedation[12] showed after 0.5-2 years a success rate of 100% for SSC for both treatment strategies. The treatment was carried out by using rubber dam. The summary of the 224 placed further restorations (amalgam, composite, composite sealants and strip crowns) showed better marginal adaptation and anatomical form after treatment under general anesthesia, compared to the results by treatment with conscious sedation.

Al Eheideb & Herman[11] treated 54 children with a mean age of 4.5 years (63% between 3-5 years old) and noticed that the survival rates for the different restorations were as follows: SSCs were, with 95.5%, the most successful type of restoration followed by the Class I amalgam restorations (93%), the Class III, IV and V composite restorations (71%) and the strip crowns (70%). The worst results were displayed by the Class II amalgam and composite restorations with a survival rate of 50%.

Of particular interest are the three investigations about the success rate of pulpotomies restored with PMCs in compari-

Table. 3. Longevity of amalgam restoratios inprimary molars(GA=general anesthesia, LA=local anesthesia, SD= study design, SM=split mouth, R=randomized, CO=controlled, C=cross-sectional, RD=rubber dam, CR = cotton rolls).

Year of publi-cation	First author	Years	Black class	Restorative materials	Restora-tions at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anesthesia	SD	Mode of isolation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
1975	Braff [9]	2.8	II	Amalgam (unspecified)	150	35	Mean 4.2; range 3-11		C		14	30.7		B2	
1980	Tonn *et al*[50]	2	II	Optaloy	105		Mean 5.9		CO	RD	94.3	2.9	Secondary caries, marginal defects	B1	Primary lesions, private practice
1980	Nelson *et al*[80]	3	II	Dispersalloy	50[29]	47			CO	RD	96.5	1.2		B1	
1981	Dawson *et al*[17]	2	I II	Amalgam (unspecified)	114 102	114	Mean 5.5		C		63.2 29.4	18.4 35.3	Recurrent caries, fractures	B2	Treatment by postgraduate students
1985	Roberts *et al*[29]	2	I & II	Ease	50 [30]	37			CO	RD	98	1		B1	
1986	Holland *et al*[26]	3	I II	Amalgam (unspecified)	704 360	317			C		42 43	19.3 19		B2	Restorations placed by under-graduate dental students
1987	Oldenburg *et al*[25]	2	I II	Sybralloy	27 34			LA	R,CO	RD	96.3 91.2	1.9 4.4		A	Primary lesions
1988	Levering & Messer[22]	5	I II	Amalgam (unspecified)	1898	226			C	RD	6876	6.44.8		B2	Restorations placed by dental students, most failures in Class II cavities of children < 4 yrs
1990	Roberts & Sheriff[16]	5	I II	Tytin	318 706	318 706		LA	CO	RD	95.9 88.4	2.8 2.3	Recurrent caries, fractures	B1	
1990	Hickel & Voss[75]	2.5	I II	Amalcap	215	74	Range 4-10		CO	CR	79.4 66.2	8.2 13.5		B1	Class II cavities were small
1990	Wong & Day[18]	5	I II	Amalgam (unspecified)	110 233				C		59.6 46.7	8.8 10.6		B2	Higher caries risk resulted in lower survival time, the older the patient , the longer the survival time
1991	Barr-Agholme *et al*[52]	2	II	Dispersalloy	55	43	Mean 6.4		CO		68	16	Caries, marginal adaptation, discol-oration at margins	A	
1991	O'Sullivan & Curzon[10]	2	I & II	Amalgam (unspecified)	106	80	Mean 4.6, range 2-11	GA	C	RD	84	8		B2	Treatment by postgraduate students, extensive caries, including formocresol pulpotomies
1991	Pieper *et al*[81]	4	I II	Amalgam (unspecified)	144 204	112			C		67 55	8.3 11.3	Marginal adaptation	B2	
1992	Ostlund *et al*[27]	3	II	ANA 2000	25[23]		Range 4-6	LA	R, CO		92	2.7		A	Second primary molars, primary lesions, small cavities,
1994	Papathanasiou *et al*[19]	5	I & II	Tytin	198	128	Range 3-10	LA	C	RD	60	8		B2	Teeth with pulpotomy included
1996	Einwag & Dunninger[20]	4.5	II		132	66			C		36	14.2	Fractures, caries	B2	
1997	Gruythuysen & Weerheijm[13]	2	I & II	Tytin	25		Mean 5.5	LA	CO	RD	68	16		B1	All teeth with pulpotomy
1997	Qvist *et al*[24]	3	I II	Dispersalloy	543[210]	254	Mean age 7; range 3-13	LA, GA	SM	CR	8582	56	Caries, fracture, loss of retention, pulpal complications	A	11 dentists placed the restorations
1997	Olmez *et al*[82]	3	II	Alloyx	50[34]	25	Range 6-9		SM		94	2		B1	Large cavities
1998	Wendt *et al*[72]	5	I & II	Amalgam (unspecified)	119		Range 3-8		C		81	3.8	Secondary caries, fractures	B2	Restorations were placed in 11 clinics in Sweden
1999	Donly *et al*[43]	3	II	Tytin	40[19]	40	Mean age 8.0	LA	SM	RD	70.6	9.8	Fracture, marginal defects, secondary caries	A	Primary lesions
1999	Marks *et al*[65]	3	II	Tytin	30 [17]	30	Mean 6.7; range 4-9	LA	SM	RD	88.2	3.9	Recurrent caries, pulpal problems	B1	Two-surface restorations, primary lesions
1999	Mass *et al*[23]	2	II	Amalgam (Non-gamma 2)	44	42	Range 3-11		CO	RD	100	0		B1	
2002	Holan *et al*[15]	2.3	I & II	Amalgam (unspecified)	54 54		Mean 6		C		80	8.7		B1	All teeth with pulpotony
2002	Duggal *et al*[28]	2	II	Contour	78[60]	78	Range 4-7	LA	SM	CR	93.4	3.3		A	Minimal Class II lesions, primary lesions

Table 4. Longevity of glass-ionomer cement restorations in primary molars (GA = General anesthesia, LA = Local anesthesia, SD = study design, SM = split mouth, R = randomized, CO = controlled, C = cross-sectional, RD = Rubber dam, CR = Cotton rolls, RMGI = resin-modified glass-ionomer, MRGI = metal-reinforced glass-ionomer).

Year of publication	First author	Years	Black class	Restorative materials	Restorations at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anesthesia	SD	Mode of isolation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
1990	Hickel & Voss[75]	2.5	I II	Ketac Silver (MRGI)	215	74	Range 4-10		CO	CR	75.5 59.2	9.8 16.3		B1	Class II cavities were small
1991	O'Sullivan & Curzon[10]	2	I & II	Glass-ionomer (unspecified)	113	80	Mean 4.6, range 2-11	GA	C	RD	71	14.5		B2	Treatment by postgraduate students, extensive caries, including formocresol pulpotomies
1991	Welbury *et al*[30]	5	I & II	Ketac Fil	119[51]	76	Range 4-10	LA (partly)	SM	CR	67	6.6	Loss of retention, secondary caries, fractures	A	
1992	Ostlund *et al*[27]	3	II	Chemfil	25[10]		Range 4-6	LA	R, CO	RD	40	20	Fractures	A	Fractures occurred mainly at the isthmus, most failures between year 1 and 2, primary lesions, small cavities
1993	Hasselrot[38]	3.5	I & II	Ketac Silver (MRGI)	36[21]				CO		9.5	25.8	Fractures, secondary caries	B2	Tunnel restorations
1995	Kilpatrick *et al*[78]	2.5	II	Ketac Silver (MRGI) Ketac Fil	92	37	Mean age 3.8; range 4-10	LA LA	SM SM		59 77	16.4 9.2	Wear, secondary caries	A A	Primary lesions, cavities cleaned with 25% polyacrylic acid for 10s
1996	Holst[37]	3	III	Ketac Silver (MRGI)	172[119]	48	Range 4-7	LA, GA	CO		49 40.5	17 19.8	Loss of retention, fractures, wear	B2	High caries risk patients, primary lesions
1997	Qvist *et al*[24]	3	III	Ketac Fil	515[143]	254	Mean age 7; range 3-13	LA, GA	SM	CR	75 58	8.3 14	Caries, fracture, loss of retention, pulpal complications	A	11 dentists placed the restorations
1998	Wendt *et al*[72]	5	I & II	Glass-ionomer (unspecified)	827	546	Range 3-8		C		91	1.8	Secondary caries, fractures	B2	Restorations were placed in 11 clinics in Sweden
1999	Folkesson *et al*[83]	3	II	Vitremer (RMGI)	174	85	Mean age 7.1; range 4-12		CO	CR	70	10	Loss of retention, secondary caries	B1	29% high caries risk patients, cavity conditioning with polyacrylic acid for 30 seconds
1999	Donly *et al*[43]	3	II	Vitremer (RMGI)	40[19]	40	Mean age 8.0	LA	SM	RD	73.3	8.9	Fracture, marginal defects, secondary caries	A	Primary lesions
1999	Espelid *et al*[39]	2.5	II	Vitremer (RMGI) Ketac Silver (MRGI)	49[25] 49[20]	43	Mean age 7.8; range 6-11		SM		98 73.5	0.8 10.6	Marginal defects, secondary caries	A	Primary lesions, small lesions
2000	Welbury *et al*[40]	3.5	I & II	Chemfil Superior	56[20]	29	Mean age 6.7; range 4-9	LA, GA	SM	CR	74	7.4	Loss of retention, secondary caries	A	Primary lesions
2001	Krämer & Frankenberger[84]	2	I II	Hi-Dense (MRGI)	54 [22]	17	Mean age 6.9; range 3-11		CO		92 66	4 17	Loss of retention, hypersensitivity	B1	
2001	Croll *et al*[42]	4 (Mean)	I II	Vitremer (RMGI)	393 406	306	Mean age 5.2; range 1-10	LA	C	RD	92.6 93.3	1.9 1.7	Material wear	B2 B2	
2002	Rutar *et al*[36]	3	I II	Fuji IX GP	56 [19] 73 [27]	69	Mean age 6.7; range 5-8	LA (partly)	CO	CR	100 93.4	0 2.2		B2	Cavities cleaned with 10% polyacrylic acid for 20 seconds; Cavity size small to medium
2003	Hubel & Mejare[41]	3	II	Vitremer (RMGI) Fuji II	53 [47] 62 [42]	40	Mean age 6.8; range 4-7	LA	SM	CR	94 81	2 6.3	Loss of retention, secondary caries, fracture	A	All cavities cleaned with 10% polyacrylic acid

son to their restoration with other materials.[13-15]

The success rate for pulpotomies in the prospective study of Gruythuysen & Weerheijm[13] at 2 years was significantly higher in teeth restored with SSCs (85%) compared to those restored with amalgams (68%).

Holan *et al*[15] evaluated 341 pulpotomized teeth restored with SSCs (287) and with amalgam (54) and concluded that the SSCs showed a lower failure rate (13%) of the pulpotomized teeth compared to those treated with multisurface amalgams (20%). They also concluded that pulpotomized primary molars could be restored with one surface amalgam if their natural exfoliation was expected after no more than 2 years.

One strong advantage of the SSC is its relative lack of sensitivity to oral conditions during placement and cementation. Even in an uncooperative child it is possible to place a well-fitting SSC without compromising the quality of the restoration. Therefore, inability to maintain the saliva contamination is an indicator for choosing the SSC as the restoration of choice.[6] In the case of pulpotomized primary molars, several investigations[13-15] showed that the failure rate of these teeth was lower by restoring them with a SSC.

Amalgam restorations

The results of clinical studies covering amalgam restorations in primary molars are summarized in Table 3. Annual failure rates for Class I amalgam restorations range between 4.4%[15] to 18.4%.[17] For Class II restorations, annual failure rates between 0%[23] to 37.2%[17] have been reported. In the few studies available on the longevity of multi-surface (>3 surfaces) amalgam restorations in primary molars, the annual failure rates were between 19%[8] and 30.7%.[9]

For Class I amalgam restorations, Qvist *et al*[24] and Oldenburg *et al*[25] reported an 85% and 96.3% survival rate resulting in an annual failure rate of 5% and 1.85%. Roberts & Sherriff[16] and Holan *et al*[15] reported annual rates in the same range (4.4%-5.3%). The highest annual failure rates of 18.4% and 19.3% were presented by Dawson *et al*[17] and Holland *et al*.[26]

For Class II restorations an 82%,[24] 91.2%,[25] 92%,[27] and 93.4%[28] survival rate was reported, leading to an annual failure rate between 2.7% and 6%.[24,25,27,28] Roberts *et al*[29] and Welbury *et al*[30] only reported of an overall success rate of 90% and 79.8%, with an annual failure rate of 5% and 4%, not finding a significant difference between Class I and Class II restorations.

One of the lowest annual failure rates of all reviewed amalgam studies was reported by Roberts & Sherriff.[16] They attributed their low rates of 5.3% (Class I) and 6.7% (Class II) to the case selection and to their specialist practice setting. Amalgam was only placed in small Class II cavities; larger defects were restored with stainless steel crowns. Additionally, more than 90% of the restorations were placed under rubber dam isolation.

Controversially, Eriksson *et al*[8] reported an annual failure rate of 18.8% using amalgam mainly to restore small lesions, allowing the conclusion that operator error might have contributed as a main source of failure.[31]

The highest annual failure rates for amalgam restorations were presented in retrospective studies,[11,17,26] with all treatments being performed by undergraduate or postgraduate students.

The need for extended clinical trials can be recognized by comparing the results of the 5-year prospective trial reported by Welbury *et al*,[30] assessing the longevity of amalgam restorations compared with GIC restorations, with the 2-year results reported of the same trial.[32] When reporting the 2-year results, the authors stated that the durability of GIC restorations was similar to amalgam restorations in primary molars. However in the subsequent 5-year follow-up the same group of workers found that GIC was significantly less durable (AFR: 6.6%, MST= 33 month) than amalgam (AFR: 4%, MST= 41 months).

The main reasons for failure were primary caries, pulpal complications and factors related to operator error,[33] insufficient marginal adaptation and secondary caries[27,30] and fracture/loss of restoration.[24,30] Additionally, Ostlund *et al*[27] noted that most of the failure occurred between the first and second years.

Overall, these findings are in agreement with practice-based studies by Mjör *et al*[34] who reported that, overall, 77% of failed amalgam restorations were replaced due to secondary caries (53%) or bulk fracture (24%). Qvist *et al*[35] supported their findings showing that Class I restorations mainly failed due to secondary caries (62%) or loose/lost restoration (18%). In Class II restorations however, the main reasons shifted towards fracture of the restoration (42%) and loose/lost restoration (30%). Only 17% of the restorations had to be replaced due to caries.

Glass-ionomer restorations

Since their introduction to dentistry in the 1970s, several studies using glass-ionomer cements (GIC) to restore primary teeth have been published. The results of clinical studies covering glass-ionomer restorations in primary molars are summarized in Table 4.

Annual failure rates for Class I restorations ranged between 0%[36] to 17%.[37] For Class II restorations, annual failure rates between 2.2%[36] to 25.8%[38] have been reported. The study by Qvist *et al*[24] reported the annual failure rate of Class I restorations. The success rate and annual failure rate of the conventional GIC tested was 75% and 8.3%. For Class II restorations, annual failure rates between 0.8%[39] to 20%[27] were found in other investigations. Welbury *et al*[30,40] reported overall success rates of 67% and 74%, resulting in annual failure rates of 6.6 and 7.4% for Class I and Class II restorations.

Besides other factors (*e.g.* pain and moisture control), one of the main reasons for the great variability in failure rates seen in all reviewed articles may be the various types of glass-ionomer cements used in the different studies.

While conventional and metal-modified GICs resulted in the highest AFR for Class I (9.8%-17%) and Class II restorations (6.3%-25.8%),[27,38,39,41] the lowest rates were reported for resin-modified GICs.[39,41,42] Hübel & Mejare[41] compared a conventional GIC with a hybrid ionomer cement and found a higher success rate for the latter. The resin-modified GIC Vitremer[a] showed a better marginal adaptation than a cermet-cement, as observed by Espelid & Tveit.[39] Donly *et al*[43] reported similar favorable results for hybrid ionomers and amalgam restorations in Class II cavities.

The main reasons for failure reported were primary caries and fractured/lost restorations. Additionally, Ostlund *et al*[27] noted that most of the failures occurred before the second year. Furthermore, Mjör *et al*[34] highlighted secondary caries as an important reason for replacement. As also seen for multi-surface amalgam restorations, the main reason for failure in Class II restorations shifted towards high fracture rates,[24] mainly at the isthmus,[27] leading to loose/lost restorations. This is particularly true for conventional GIC and cermet cements. Resin-modified GICs exhibited a reduced risk of fracturing of approximately 50% compared to conventional GIC.[34] Overall, these findings are thought to be due to inadequate mechanical and handling properties and therefore conventional and metal-modified GICs can no longer be recommended as a restorative material (especially in Class II restorations) in the primary dentition.[39] For high viscosity GIC in primary molars, sufficient longevity data are still lacking.

Atraumatic restorative treatment (ART)

The atraumatic restorative treatment (ART) approach for primary teeth has achieved considerable interest worldwide, especially for its application in developing countries where highly trained dental personal and the electricity needed for clinical equipment are not available. This technique involves the use of hand instruments only to remove carious tooth substance before the cavity is restored usually with a conventional, self-hardening glass-ionomer cement (GIC).[44,45] There are relatively few investigations about this treatment approach in the primary dentition.[44] The literature search had an outcome of four articles[46-49] that fulfilled the selection criteria. In all these studies, the children treated had a high caries risk or prevalence measured by the dmft. The results of clinical studies covering ART restorations in primary molars are summarized in Table 5.

Lo & Holmgren,[46] in a controlled clinical study, reported the results from 170 ART restorations placed in 95 children and followed up by two calibrated examiners every 6 months for 2.5 years. The mean age of the treated children was 5.1 years. Teeth with pulpal exposure were excluded from the study. The material used was a hand mix, high-strength glass-ionomer, Ketac Molar.[a] The conditioner used was the liquid component of the GI diluted with an equal amount of water. The press-finger technique was used to condense the material into the cavity. No varnish was applied. The survival rate for the Class I restorations after 2.5 years was 76%. Class II restorations showed a lower survival rate of 54% for the same time. Class III and IV restorations succeeded in 14% and Class V restorations in 73%. The ART approach was in this study shown to be highly acceptable to Chinese preschool children. The 2.5-year success rates were high for Class I and V restorations.

Lo *et al*[47] compared the clinical performance of two glass-ionomer cements when used with the atraumatic restorative treatment approach in China. Matched pairs (92) of carious posterior teeth in a split-mouth design were treated randomly with the two materials and followed up over 2 years. The survival rates in the primary teeth of the 82 children evaluated after 2 years were 93 and 90% for the CemFlexa and Fuji IX GPb Class I restorations, respectively. The survival rates for the Class II restorations were 40 and 46%. All restorations were placed by one experienced dentist. Although the restorations in the study were not placed in a dental clinic under optimal conditions, their placement by an experienced dentist, together with the use of a trained assistant, brought the authors to suppose that these parameters might have helped to produce the good results. Based on the findings of this study, it was concluded that the clinical performance and occlusal wear pattern of the used materials were similar. Both materials were satisfactory and adequate for use with the ART approach to restore

Table 5. Longevity of ART restorations in primary molars (GIC = Glass-ionomer cement, GA = General anesthesia, LA = Local anesthesia, SD = study design, SM = split mouth, R = randomized, CO = controlled, C = cross-sectional, RD = Rubber dam, CR = Cotton rolls).

Year of publication	First author	Years	Black class	Restorative materials	Restorations at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anesthesia	SD	Mode of isolation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
2001	Lo *et al*[47]	2	I CF I Fuji II CF II Fuji	GIC (ChemFlex & Fuji IX GP)	97[78]	89	Range 6-14		SM		96 92 41.7 46.2	2 4 29.1 26.9	Loss of retention, marginal defects	A	Cavities were cleaned with GC dentin conditioner
2001	Lo & Holmgren[46]	2.5	I II	GIC (Ketac Molar)	170 [116]	95	Mean age 5.1	No LA	CO	CR	76 54	9.6 18.4	Loss of retention, caries, marginal defects	B1	High caries risk children in China, teeth were conditioned with liquid if GIC, treatment by final-year students
2002	Taifour *et al*[48]	3	I II	GIC (Fuji IX & Ketac Molar)	476 610	482	Range 6-7		CO	CR	86.1 48.7	4.6 17.1	Loss of retention, fractures, marginal defects	B1	High caries risk children, 8 dentists placed the restorations
2003	Honkala *et al*[49]	2	I II	GIC (ChemFlex)	49 12	35	Mean age 5.7; range 2-9	No LA	CO		93.7 83.3	3.2 8.4		B1	High caries risk children

Class I cavities.

Taifour *et al*[48] carried out a 3-year clinical investigation to evaluate the effectiveness of ART restorations compared to a modified traditional approach of amalgam restorations (MTA) which was different as it did not use the extension for prevention concept in the primary dentition. A total of 482 children were treated through the ART and 353 through the MTA approach using a parallel group design. The study revealed a 3-year cumulative survival percentage of single-surface ART and MTA restorations of 86.1 and 79.6%. Those of the multisurface ART and MTA restorations were 48.7 and 42.9%. The authors concluded that the ART approach using GI yielded better results than did the traditional approach using amalgam after 3 years.

Honkala *et al*[49] reported in an approximately 2-year clinical investigation the results of 35 treated children with a mean age of 5.7 years. Eighteen of them had comparable pairs of restorations (70 restorations in 35 teeth). The other 17 children had received only ART restorations (48). A total of 89.6% of all ART restorations were considered successful. The most successful group was that of the Class I restorations with a success of 93.7%. The group with the comparable pairs of restorations showed a success rate of 93.4% for both the ART and the amalgam restorations. But the fact of the high success rates in this study might be due to the small sample size and the higher than expected drop-out rate (17%). The authors concluded that the ART approach is an appropriate treatment option for primary teeth in industrialized countries. It is not the only treatment option but could be used successfully in Class I restorations of primary teeth.

Composite restorations

Composites are widely used for restoring primary posterior teeth in stress-bearing areas. The results of clinical studies covering composite restorations in primary molars are summarized in Table 6.

Studies comparing the clinical success of composites to amalgam in primary molars have shown contradicting results. Whereas in the earliest study, Tonn *et al*[50] had to replace more composite than amalgam restorations, Roberts *et al*[29] and Oldenburg *et al*[25] could not report any statistically significant difference in the clinical performance of composite *versus* amalgam restorations in primary molars. In the study by Oldenburg *et al*,[25] an experimental composite was compared with an amalgam alloy in 152 Class I and Class II restorations in primary molars. Additionally, 183 Class I restorations were placed in first permanent molars. After 2 years, little difference was observed between the two materials, except for wear, which was higher in teeth with composite restorations.

Later, Barr-Agholme *et al*[52] showed that the success rate of Class II composite restorations was significantly higher than for amalgam and was neither influenced by the age of the patient nor the caries activity nor the tooth on which the restoration was done (first or second primary molar). On the other hand, Leifler & Varpio[53] found composite to be inferior to amalgam when they compared their results to similar studies that used amalgam. It must be stated though, that this study, published 10 years earlier, had a very long etching time of 2 minutes and that no bonding resin was used, which might be a reason for the high failure rate.

Bevan & Braham[54] compared the handling properties of a composite and an amalgam material and came to the conclusion that composite required a highly skilled clinical technique and longer working time and is therefore not recommended as a replacement for amalgam. Cunha[55] recommended composite restorations for the late mixed dentition because of similar wear to primary enamel.

The only study that compared preventive resin restorations or occlusal composite restorations of minimal size in permanent molars and premolars to primary molars was that of Granath *et al.*[56] Both groups did not display any ratings below Bravo.

Kimura *et al*[57] evaluated the clinical performance of a light-cured composite in primary molars and incisors and found no difference between the results of the two groups. Motokawa *et al*[58] placed 50 Class I and Class II composite inlays in primary molars with 90% of them rated satisfactory after 2 years. Of the five failures, four were due to fractures.

Oldenburg *et al*[59] used two experimental composites in three different cavity preparations in the primary molars of 50 children. A total of 357 restorations were placed. After 4 years, 130 restorations were still available for evaluation. The differences between the two materials were not significant but in clear favor for one of the materials. Of the 39 failures, 34 had occurred in Class II restorations. The minimally invasive modified cavity preparation could not be recommended, as it had a 34% failure rate. Tonn & Ryge[51] found very favorable results for a composite in a 4-year study.

The longest running study on composite restorations in primary molars was published by Varpio[60] in 1985. At the final examination after 6 years, 46% of the restorations were rated as failures. Most of the fractures were found during the first year, recurrent caries could be detected in the second year and reduced occlusal height and color mismatch followed after the third and fourth year. Vann *et al*[61] and Wendell & Vann[62] especially looked at wear rates of composite restorations in primary molars. Progressive wear could be shown over time although it was also stated that the USPHS evaluation criteria are insensitive in detecting early wear in primary molars.

Compomer restorations

The term "compomer" is comprised by syllables of the words "composite" and "glass-ionomer". This class of restorative materials, also called polyacid-modified resins, combines some of the material properties of composites with some of glass-ionomer cements. Compomers (Dyract[a]) were introduced in the market in 1993/94. Compomers are in their chemical structure similar to composites. However, they include reactive, ion-leachable glass particles and polymerizable acidic monomers. In contrast to glass-ionomers, compomers contain no water in their formulations and are one-component materials (with the exception of dual-curing compomers for cementation purposes, *e.g.* Dyract Cema), which do not need mixing. An acid-base reaction, which is typical for the setting mechanism of for GICs and hybrid ionomers does not occur during the setting process of compomers. For the latter, a minor acid-base reaction occurs only when the restoration absorbs water mediated by saliva.

With regard to the mechanical properties, in particular tensile strength and flexural strength, as well as wear resistance, compomers are superior to GICs and hybrid ionomers. However, these materials exhibit a wide range of data within mate-

Table 6. Longevity of composite restorations in primary molars (GA = General anesthesia, LA = Local anesthesia, SD = study design, SM = split mouth, R = randomized, CO = controlled, C = cross-sectional, RD = Rubber dam, CR = Cotton rolls).

Year of publi-cation	First author	Years	Black class	Restorative materials	Restora-tions at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anes-thesia	SD	Mode of iso-lation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
1980	Tonn *et al*[50]	2	II	Epoxydent	105		Mean 5.9		CO	RD	87.6	6.2	Secondary caries, marginal defects	B1	Chemically cured composite, tooth conditioning with 50% citric acid, primary lesions, private practice
1980	Nelson *et al*[80]	3	II	Adaptic	50[28]	47			CO	RD	96.4	1.2		B1	
				Adaptic Radiopaque	50 [27]	47					96.3	1.2			
1985	Varpio[60]	6	II	Concise Cap-C	91 [53]		Mean 7.4		CO	RD	38	10.3	Fractures, secondary caries	B1	Chemically cured composite, primary lesions, no bonding, no adhesive
1985	Roberts *et al*[29]	2	I & II	Profile	61 [37]	37			CO	RD	91.9	2.7	Secondary caries, fracture, marginal defects	B1	Chemically cured composite, selective enamel etch for 90s with 50% H3PO4, only enamel bond
1987	Oldenburg *et al*[25]	2	I & II	H-120	91	41	>7	LA	CO	RD	98.9	0.6		B1	Selective enamel etch for 90s with 50% H3PO4, primary lesions, bulk technique, only enamel bonding
1987	Oldenburg *et a*[59]	4	I & II	Ful-fil X-55	357 [130]	50 [48]	Range 4-8	LA	CO	RD	75.9	6	Secondary caries, fractures	A	Primary lesions, only selective enamel etch, only enamel bonding, composite placed in bulk technique
1988	Tonn & Ryge[51]	4	I & II	Ful-fil	96 [44]	44 [26]	Mean 5.8, range 3-8	LA	CO	RD	95.6	1.1	Marginal adaptation	B1	90s acid etched, PrismaBond on enamel
1990	Motokawa & Braham[58]	2	I & II	P30	50	40	Mean 6.5, range 3-11		CO		90	5	Fractures at isthmus	B1	Composite inlays, total etch with H3PO4
1991	O'Sullivan & Curzon[10]	2	I & II	Composite (unspecified)	113	80	Mean 4.6, range 2-11	GA	C	RD	71	14.5		B2	Treatment by postgraduate stu-dents, extensive caries, including formocresol pulpotomies
1991	Barr-Agholme *et al*[52]	2	II	P30	64	43	Mean 6.4		CO		88	6	Caries, marginal adaptation, dis-coloration at margins	A	Selective enamel etch for 15s with 37% H3PO4, primary lesions
1992	Ostlund *et al*[27]	3	II	Occlusin	25 [19]		Range 4-6	LA	R, CO	RD	84	5.3	Secondary caries, fracture	A	Second primary molars, small cavities, conditioning 60s with H3PO4, primary lesions, 2mm incremental placement
1992	Granath *et al*[56]	2		Occlusin	35		Range 5-14		C	CR	91	4.5	Marginal adapta-tion, marginal discoloration	B2	Restorations mainly placed by dental students
1994	Papathanasiou *et al*[19]	2.7	I & II	Occlusin	173	128	Range 3-10	LA	C	RD	40	15	Caries	B2	Teeth with pulpotomy included, placed by students
1997	Olmez *et al*[82]	3	II	Superlux resin	50 [34]	25	Range 6-9		SM		100	0		B1	Large cavities
1998	Wendt *et al*[72]	5	I & II	Composites	87		Range 3-8		C		88	2.4	Secondary caries, fractures	B2	Restorations were placed in 11 clinics in Sweden
1999	Kimura *et al*[57]	3	I	Estio LC	28				CO		92.9	2.4		B1	Primary lesions
2000	Cunha[55]	2.5	I	TPH Spectrum	49 [39]	30	Range 5-8	LA	CO	RD	100	0		B1	Enamel etch for 60 s, restorations were not polished.
2001	Attin *et al*[67]	3	II	TPH Spectrum	96 [46]	52 [35]	Range 4-11	LA	R, SM	CR	85.8	4.7	Caries	A	Total etch, Kaplan-Meier, Restorations with pulp amputation showed inferior results

rial properties among different products. Most of them do not quite achieve the material properties of hybrid composites but are often superior to microfilled composites.[63,64] Prior to the application of the compomer, the enamel and dentin needs to be primed by a bonding agent, to obtain optimum adhesion and bond strength to the hard tooth tissues. GICs bond chemically to the tooth structure, partially by chelation of the calcium in the apatite of enamel and dentin with the carboxyl groups of their polyacids. In contrast, bonding to tooth structure by compomers is primarily mediated by micromechanical retention (resin tags and resin-dentin-interdiffusion zone = hybrid layer), like the dentin adhesive/composite systems. Compomers are chemically more similar to composites than to conventional GICs. Compomers have rapidly gained a large market share especially in Europe. Concerning esthetics and finishing/polishing procedures, compomers are superior to conventional and even resin-modified GICs. They match almost perfectly with the surrounding tooth structure, unlike GICs, which sometimes look chalky and opaque. The results of clinical studies covering compomer restorations in primary molars are summarized in Table 7.

Marks *et al*[65] reported after 3 years of clinical service a success rate of 94.1% for Dyract compomer restorations in primary two-surface lesions that were isolated with rubber dam at placement time. Main failure reason was recurrent caries. Roeters *et al*[66] stated after the same observation time a success rate of 89.2% for Class I and II compomer restorations. These restorations were placed without phosphoric acid etching of dental substrates and with cotton roll isolation of the operating field. Considerable amounts of wear were observed.

Attin *et al*[67] reported a success rate of 79.5% for Class II compomer restorations after 3 years of service. These restorations had also been placed without phosphoric acid etching of dental substrates and with cotton roll isolation of the operating field. Main failure reasons were caries and fractures. Restorations with pulp amputations exhibited inferior clinical performance. Papagiannoulis *et al*[68] reported a 90% survival of compomer restorations after 2 years that were placed with rubber dam isolation but without phosphoric acid etching. All were primary caries lesions and all teeth were vital. Failure reasons were dominated by secondary caries formation and bulk fracture. Mass *et al*[23] showed a survival rate of 100% for Class II compomer restorations after 2 years, that were placed without additional etching and under rubber dam isolation. Gross *et al*[69] compared two compomers (Hytac and Dyract) in his 2-year Class II study and found a survival rate of 93 and 96% for both materials, being not statistically significant. All teeth were vital and the restorations were placed under rubber dam isolation.

Andersson-Wenckert *et al*[70] reported a success rate of only 78% after 2 years for Class II compomer restorations in a multicenter study. Krejci *et al*,[71] however, found perfect survival of 100% after the same study duration for the same compomer restorative (Dyract) in Class II cavities as well. Duggal *et al*[28] stated a success rate of 96.6% for minimal Class II restorations for the treatment of primary caries. After 3.5 years of service, Welbury *et al*[40] detailed a success rate of 74% for Class I and II compomer restorations after primary caries therapy. In a retrospective study, Wendt *et al*[72] exam-

Table 7. Longevity of compomer restorations in primary molars (GA = General anesthesia, LA = Local anesthesia, SD = study design, SM = split mouth, R = randomized, CO = controlled, C = cross-sectional, RD = Rubber dam, CR = Cotton rolls).

Year of publication	First author	Years	Black class	Restorative materials	Restorations at study start[end](n)	Patients at study start[end](n)	Patients' age (years)	Mode of anesthesia	SD	Mode of isolation	Success rate (%)	Annual failure rate	Main failure	Evidence level reasons	Remarks
1997	Andersson-Wenckert[70]	2	II	Dyract	159 [104]	79	Mean 7.4		CO	CR	78	11	Secondary caries, loss of retention	B1	Multi-center study (6 different centers)
1998	Roeters[66]	3	I and II	Dyract	91 [37]	55	Mean 7; range 4-9		CO	CR	89.2	3.6	Fractures, loss of retention	B1	No etching only primer
1998	Krejci[71]	2	II	Dyract	29 [22]	17	Range 7-12		CO	RD	100	0		B1	No etching only primer
1998	Wendt[72]	5	I and II	Compomers	1040	546	Range 3-8		C		91	1.8	Secondary caries, fractures	B2	Restorations were placed in 11 clinics in Sweden
1999	Marks[65]	3	II	Dyract	30 [17]	30	Mean 6.7; range 4-9	LA	SM	RD	94.1	2	Recurrent caries	B1	2-surface restorations, primary lesions
1999	Papagiannoulis[68]	2	II	Dyract	68 [55]	25	Mean 7.5; range 6-9		CO	RD	90	5	Secondary caries, bulk fracture	B1	No etching only primer, primary lesions
1999	Mass[23]	2	II	Dyract	63	42	Range 3-11		CO	RD	100	0		B1	No etching only primer
2000	Welbury[40]	3.5	I and II	Dyract	56 [15]	29	Mean 6.7; range 4-9	LA, GA	SM	CR	91	2,6	Fracture, loss of retention	A	No etching only primer, primary lesions
2001	Attin[67]	3	II	Compoglass	94 [46]	52 [35]	Range 4-11	LA	R, SM	CR	79.5	6.8	Caries, fractures	A	No etching only primer; Kaplan-Meier, teeth with pulp amputation showed inferior results
2001	Gross[69]	2	II	Dyract, Hytac	49	49	Range 5-8	LA	R, SM	RD	Dyract 96, Hytac 93	Dyract 2, Hytac 3.5	Secondary caries	A	High caries risk children, primary lesions
2002	Duggal[28]	2	II	Dyract	78 [60]	78	Range 4-7	LA	SM	CR	96.6	1.7		A	Minimal class II and primary lesions

Table 8. Influence of cavity class and publication date on mean annual failure rates (%) of amalgam restorations in primary molars (n= number of studies).

Amalgam	Studies 1971 – 1987	Studies 1988 - 2003
Class I	13.2 % (n=3)	6.6 % (n= 6)
Class II	13.4 % (n=7)	7.6 % (n=18)

Table 9. Influence of cavity class on mean annual failure rates (%) of different types of glass-ionomer restorations in primary molars (n= number of studies). In the column GIC studies, conventional and high viscosity GIC were pooled.

GIC	GIC studies 1990 - 2003	A.R.T. studies 2001 – 2003	RMGI studies 1998 – 2003
Class I	7.8 % (n=5)	4.7 % (n=4)	1.9 % (n=1)
Class II	13.9 % (n=11)	20.0 % (n=4)	4.2 % (n=6)

Table 10. Success rates (%) of restorations in primary molars distinguished by materials and observation period.

	Study duration (yrs)	2	3	4	5	6	7	8	9
Stainless steel crowns (SSC)	Mean	86.6	58		86.7	83	88		
	Min.	75	58		68			83	88
	Max.	97	58		100			83	88
	Number of readings	7	1		3			1	1
Amalgam	Mean	80.5	67.8	61	72.2				
	Min.	29.4	14	55	36				
	Max.	100	96.5	67	95.9				
	Number of readings	12	12	2	7				
Glass-ionomer	Mean	80.1	66.8	67.4	79				
	Min.	66	16.3	9.5	67				
	Max.	98	100	93.3	91				
	Number of readings	5	15	4	2				
ART restorations	Mean	75.5	66.2						
	Min.	41.7	54						
	Max.	96	86.1						
	Number of readings	6	4						
Composite	Mean	89.8	85.1	85.8	88	38			
	Min.	71	40	75.9	88	38			
	Max.	100	100	95.6	88	38			
	Number of readings	8	7	2	1	1			
Compomer	Mean	93.3	87.6	91	91				
	Min.	78	79.5	91	91				
	Max.	100	94.1	91	91				
	Number of readings	7	3	1	1				

ined 1040 compomer restorations and found a success rate of 91% after 5 years. The restorations were placed in 11 clinics in Sweden.

Mean annual failure rates of studies published in 1988 and after are detailed in the Figure. Statistical analysis with ANOVA and post hoc LSD-test exhibited a significantly higher annual failure rate (13.9%) for GIC restorations compared to all other types of restorations which were in the same homogeneous subset. Table 8 details the influence of cavity class and publication date on annual failure rates (%) of amalgam restorations in primary molars. Older studies, covering the publication time from 1971 to 1987 exhibited drastically higher failure rates compared to studies published within the last 15 years. Cavity class (Black I *vs* II) had almost no influence on failure rate of amalgam restorations; however with glass-ionomer restorations (Table 9), Class II cavities exhibited a distinct higher failure rate than Class I restorations. This may be attributed to the low flexural strength of conventional glass-ionomer materials which are challenged even in occlusally-loaded cavities of primary posterior teeth. RMGI showed a much better behavior in Class II cavities.

Discussion

The longevity of dental restorative materials used in the primary dentition has been reviewed by Kilpatrick[73] over 10 years ago, who highlighted a great variability in the success rates. This could be confirmed by the results of the present review (Table 10). The clinical success of dental restorations is dependent upon many different factors, such as materials- (Table 11), dentist-, and patient-related factors. Compared to the permanent dentition, the longevity of restorations in primary teeth is significantly different for all materials. This makes the assessment of these restorations as a separate group meaningful.[74]

Variables like the use of anesthesia, nitrous oxide/local analgesia, or the type of moisture control have been reported to influence the outcome of clinical trials in pediatric dentistry.[16] One factor usually mentioned to be a determinant in restoration longevity in primary teeth is the patient's age at restoration placement.

According to Holland *et al*,[26] the failure of amalgam restorations occurs more frequently in primary teeth, especially in small children, due to moisture contamination of the cavities during condensation. The age of the children at the time of placement is therefore a major factor in restoration longevity.[26,52,75] Several studies showed a relationship between the patient's age at the time of placement and the longevity of dental restorations.[18,22,26,39,75,76] Several authors found an average longevity of less than 2 years for amalgam restorations in children 4 years old and younger. The lifespan of composite restorations in this age group dropped to only 1 year.[26,33,77] It is assumed that the failure of amalgam and composite restorations occurs more frequently in primary teeth, especially in small children, due to moisture contamination of the cavities during the placement of the restorative material.[26] However, in children older than 5 years, two studies could not verify

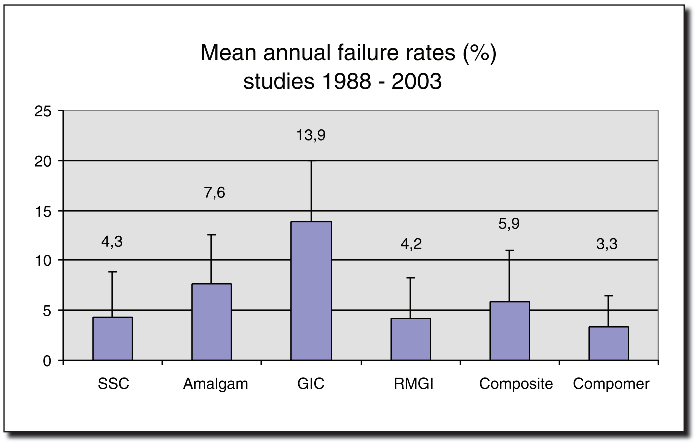

Figure. Mean annual failure rates of different types of restorations in primary molars. Statistical analysis with ANOVA and LSD-test exhibited a significantly higher failure rate for GIC restorations compared to all other types of restorations which were in the same homogeneous subset.

any relationship between the restoration longevity and the age of patients.[16,78] When treating children between the age of 4-7 (mean age: 6.2), Hubel & Mejare[41] were also unable to show a significant influence of the patients age on the success rate. Even though Barr-Agholme *et al*[52] were able to show an increasing 2-year success rate of composite and amalgam restorations for 7-8 year-old patients compared to 4-6 year-olds, (composite 4-6 years: 80% , 7-8 years: 100%; amalgam: 4-6 years: 63%, 7-8: 80%), statistical analysis also did not reveal a significant influence of patients age on the success rate of proximal restorations.

In spite of substantial improvements during the 1980s, the conventional glass-ionomer cements still show shortcomings with regard to moisture sensitivity, wear resistance, flexural strength, and final polishing.[74] Even though the chemical adhesion to enamel and dentin and the fluoride release are major benefits, conventional GICs have only special indications (Class III and Class V cavities) in operative dentistry. The use of conventional GICs and cermet-cements has decreased, due to the development of new restorative materials, such as composites and compomers. However, conventional GICs still may be an important alternative restorative material for patients suffering from allergies *e.g.* to polymerizable resin monomers.

Resin-based composites and compomers have become increasingly popular for the restoration of carious primary molars. In some European countries, these materials are preferred for restoring primary molars because of the controversy over dental amalgam and its alleged adverse health effects resulting from mercury release and restrictions of health authorities, although a clear correlation between amalgam restorations and health has not been determined yet.[79] Also, esthetic considerations of the patients' parents promote the use of tooth-colored restoratives even in primary molars.

Stainless steel crowns are still the restorative procedure of choice for severely affected primary molars; however, especially in smaller cavities, the adhesive technique with compomers and composites can be used in a great number of cases when the child is cooperative. Important parameters such as patients' cooperation during treatment, caries activity, different material performances within one group of restorative materials and operator's experience (examined dentist *vs.* dental student) affect clinical longevity of restorations in primary molars, but could not be analyzed statistically due to inadequate reporting in many of the retrieved articles.

Table 11. Differences in material performance in studies comparing different types of restorative materials (number of studies).

Material 1	Material 2	Mat.1 shows significantly better clinical performance than Mat. 2	Mat. 2 shows significantly better clinical performance than Mat. 1	No signi-. ficant difference between Mat. 1 and 2
Amalgam	SSC		7	1
Amalgam	GIC conventional	2	1	2
Amalgam	RMGI			1
Amalgam	Composite		1	3
Amalgam	Compomer		1	1
Composite	Compomer			1
RMGI	GIC conventional	2		
Compomer	GIC conventional	1		

a. Dentsply DeTrey, Konstanz, Germany.
b. GC Corp., Tokyo, Japan.
c. 3M ESPE, St. Paul, MN, USA.

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