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An Evaluation of Replacement Rates for Posterior Resin-Based Composite and Amalgam Restorations in U.S. Navy and Marine Corps Recruits

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An evaluation of replacement rates for posterior resin–based composite and amalgam restorations in U.S. Navy and Marine Corps recruits

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ABSTRACT

Background. Restoration replacement is a clinical concern that has not been studied among military personnel. The authors determined the prevalence of placement of posterior amalgam and resin-based composite restorations and the incidence of replacement among U.S. Navy and Marine Corps personnel.

Methods. The authors analyzed dental records from 2,780 personnel to determine the relative risk of replacement for initially sound restorations during subjects' first years of military service.

Results. At the initial examination, 964 (15.2 percent) of amalgam restorations and 199 (17.4 percent) of resin-based composite restorations required re-treatment. Of those judged clinically acceptable, 14.2 percent of amalgam and 16.7 percent of resin-based composite restorations required replacement during the observation period. The authors found significant increases in replacement rates for resin-based composite restorations compared with amalgam restorations for replacement due to all causes (adjusted hazard ratio, 1.28; $P < .05$), as well as for replacement due to restoration failure (adjusted hazard ratio, 1.64; $P < .01$).

Conclusions. About 30 percent of posterior restorations required replacement, either at the initial examination or during the subjects' first years of military service. In a young military population, significantly more resin-based composite restorations in place at the initial examination will require replacement than will amalgam restorations. Multisurface restorations had higher rates of replacement than did one-surface restorations, and subjects at high caries risk experienced significantly higher replacement rates than did those at low caries risk.

Clinical Implications. The number of surfaces restored and subjects' caries risk status may influence the longevity of resin-based composite and amalgam restorations.

Key Words. Amalgam; resin-based composite; posterior restorations.
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The U.S. Navy dental care system accepts approximately 70,000 new patients every year into its care and must determine the best course of treatment to achieve and maintain their optimal oral health. Treatment needs among new recruits vary considerably. Similarly, the extent of previous care is quite diverse. Moreover, the type and number of existing restorations in incoming recruits are not readily predictable, and possible differences in replacement rates for restorative materials complicate treatment planning.

RESIN-BASED COMPOSITE AND AMALGAM RESTORATIONS

The availability of resin-based composite materials, which are more esthetically pleasing than dental amalgam, has prompted many private practitioners to use them for posterior restorations. A recent study by Beazoglou and colleagues[1] reported that U.S. dentists placed more resin-based composite than amalgam restorations during 2005. Of the 166 million restorations placed that year, 46.6 percent were resin-based composite, while only 31.6 percent were amalgam.[1] A survey of 714 members of the Academy of General Dentistry revealed that more than 30 percent considered their practices to be "amalgam-free."[2]

Longevity. The longevity of pos-

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terior dental materials has been studied extensively, but only a small number of the evaluations compared dental amalgam with resin-based composite restorations in posterior teeth. We reviewed 12 studies that compared amalgam and resin-based composite restorations in posterior teeth. Even though they did not all show statistical differences, results from nine studies [3-11] suggested the superiority of amalgam over resin-based composite, while results from three studies[12-14] suggested that resin-based composite was equal or superior to amalgam. The majority of studies[3,5,6,10,11,13,14] compared amalgam with resin-based composite restorations in populations in Europe. Only three studies[4,8,12] compared materials in subjects in the United States.

Randomized studies. Bernardo and colleagues[3] found that amalgam performed better than resin-based composite restorations across a seven-year evaluation. They randomly placed 1,748 amalgam and resin-based composite restorations in 472 children aged 8 to 12 years. The survival rate for amalgam (94.4 percent) was significantly greater than that for resin-based composite (85.5 percent). The risk of fracture was similar for both materials, but the risk of secondary caries was significantly higher for resin-based composite than for amalgam (relative risk, 3.5; $P < .001$).

Soncini and colleagues[4] also observed a greater (although not statistically significant) longevity for amalgam restorations than for resin-based composite restorations. They randomly placed 1,262 resin-based composite and amalgam restorations in permanent posterior teeth of 6- to 10-year-olds. The replacement rate during the five-year follow-up period was 10.8 percent for amalgam and 14.9 percent for resin-based composite, while 14.2 percent of large amalgam restorations and 19.8 percent of large resin-based composite restorations required replacement. The most frequent reasons for replacement were new caries (amalgam, 40 percent; resin-based composite, 33 percent) and recurrent caries (amalgam, 44 percent; resin-based composite, 52 percent).

Norman and colleagues[12] randomly placed 107 resin-based composite and 53 amalgam restorations in 62 patients. After five years, three amalgam (5.7 percent) and six resin-based composite (5.6 percent) restorations failed. They concluded that resin-based composite was as effective as amalgam when occlusal wear, marginal adaptation, anatomical form and interproximal contacts were compared.

Mair[13] studied 90 resin-based composite and 60 amalgam restorations, the majority of which were placed randomly in dental students. After 10 years, 55 resin-based composite and 37 amalgam restorations were available for evaluation. None of the restorations evaluated at the 10-year recall visit required replacement. However, the author reported that four resin-based composite and two amalgam restorations had failed before the 10-year follow-up.

Prospective studies. Van Nieuwenhuysen and colleagues[5] studied extensive amalgam (n = 722) and resin-based composite (n = 155) restorations in subjects with a median age of 40 years (range, 16-80 years). All of the restorations evaluated were replacements and placed as alternatives to crowns. More than 60 percent of the teeth had been treated endodontically. At follow-up, when the authors considered repairs, replacements and extractions to be failures, amalgam showed superiority, with a median survival of 12.8 years, compared with a median survival of 7.8 years for resin-based composite. The authors did not recommend resin-based composite restorations as an alternative to crowns.

Mjör and Jokstad[6] studied the outcomes of 179 Class II restorations (88 amalgam and 91 resin-based composite) placed in adolescents. The estimated survival at five years was significantly greater for amalgam than for resin-based composite. Collins and colleagues[7] evaluated 213 Class I and II resin-based composite and amalgam restorations placed in 46 patients across an eight-year follow-up period (1986-1994). The rate of failure for resin-based composite restorations was more than twice that for amalgam restorations (amalgam, 5.8 percent; resin-based composite, 13.7 percent). Moffa[8] reported the results of a large study of resin-based composite (n = 609) and amalgam (n = 1,517) restorations. The results of that study showed a greater longevity for amalgam, with 65.5 percent of amalgam and 41.7 percent of resin-based

ABBREVIATION KEY. DO: Disto-occlusal. **DTFs:** Dental treatment facilities. **MO:** Mesio-occlusal. **MOD:** Mesio-occlusodistal. **NIDBR:** Naval Institute for Dental and Biomedical Research. **ODRM:** Oral Disease Risk Management. **RERs:** Replacement of existing restorations. **SOAP:** Subjective findings, objective findings, assessment, plan.

composite restorations determined to be functional after 12 years.

Retrospective studies. Opdam and colleagues[14] reported survival results for 2,867 Class I and II amalgam and resin-based composite restorations placed in 621 patients by two general dentists. The clinicians used amalgam for the larger restorations and resin-based composite for the smaller restorations. Resin-based composite restorations exhibited a slightly greater (although not statistically significant) survival than amalgam restorations at 10 years (82.2 percent versus 79.2 percent).

Levin and colleagues[9] evaluated bitewing radiographs obtained from 459 adults aged 18 to 19 years who underwent dental screening before military service. Among 650 interproximal restorations (557 amalgam, 93 resin-based composite), the failure rate as a result of secondary caries was 8 percent for amalgam and 43 percent for resin-based composite. Mjör and colleagues[10] reported the reasons for replacement of amalgam and resin-based composite restorations placed by 243 Norwegian dentists. The mean ages of failed amalgam restorations were 10 and 11 years for Class I and II restorations, respectively, while the mean ages of failed resin-based composite restorations were statistically lower (six years) for both Class I and II restorations.

Jokstad and colleagues[11] evaluated randomly selected patient treatment records; they assessed 3,853 amalgam and 83 resin-based composite restorations (Class I and Class II: mesio-occlusal [MO], disto-occlusal [DO], mesio-occlusodistal [MOD]). For each type of restoration, the study results showed that the median age of amalgam restorations was greater than that of resin-based composite restorations (Class I, 14 years versus four years; Class II MO or DO, 11 years versus five years; and Class II MOD, 11 years versus four years).

Restoration longevity is critical to the military, as well as to any public health care system, because a significant increase in the risk of failure could impose a substantial increase in overall treatment requirements and subsequent costs. Of even more importance to the military is the possibility of restoration failure during operational deployments, which has been shown to be a significant problem in all services. Defective restorations accounted for 23 percent of all dental emergencies among U.S. Army personnel deployed to Bosnia in 2000 and 2001.[15] Caries and defective restorations accounted for 39 percent of all dental emergencies experienced by Marines ashore during Operation Desert Shield/Desert Storm in 1990 and 1991.[16]

Military personnel often are placed in hostile environments where dental care may not be available or is available only by traveling through potentially dangerous areas. For obvious reasons, minimizing the risks of such dental emergencies is paramount. Leinfelder[17] reported that amalgam restorations are expected to be clinically serviceable for 10 to 12 years, while resin-based composite restorations are expected to last only one-half as long. One reason for the greater risk of secondary caries associated with resin-based composites is their lack of the bacteriostatic elements (such as silver) that make up dental amalgam. Not only is there no element to promote bacteriostasis, but the constituents of resin-based composite actually may encourage the growth of microorganisms.[17] Moreover, the finding by Levin and colleagues[9] that a large percentage of teeth in young adults with interproximal resin-based composite restorations developed secondary caries may justify a lack of confidence in these restorations placed in posterior teeth, especially those placed in interproximal cavity preparations.

Although the status of pre-existing restorations is documented at recruits' initial dental examination, neither the prevalence of nor the replacement rates for posterior amalgam and resin-based composite restorations have been evaluated in U.S. Navy or Marine Corps personnel. Therefore, we conducted a study to determine the frequency of replacement during the first years of military service for restorations deemed clinically acceptable at the initial examination, as well as whether the frequency of replacement differed on the basis of the restorative material, restoration size (number of surfaces) or subject's initial caries risk status.

SUBJECTS, MATERIALS AND METHODS

Sampling method. In 2000, we initiated a study of the dental treatment needs of, and outcomes for, U.S. Navy and Marine Corps personnel in which two of us (J.W.S., K.E.D.) reviewed cluster samples of dental records maintained at 16 U.S. Navy dental treatment facilities (DTFs) in the continental United States. All personnel who entered the U.S. Navy in 1997 (cohort 1) or the U.S. Marine Corps in 1999 through 2000 (cohort 2) or October 2002 through July 2005 (cohort 3)

were eligible for inclusion into the study. Staff members from the Naval Institute for Dental and Biomedical Research (NIDBR), Great Lakes, Ill., traveled to the 16 DTFs, identified potential subjects, and located and collected the subjects' dental records. We collected the dental records for cohort 1 during 2001, cohort 2 during 2002 and 2003 and cohort 3 during 2005 and 2006. To ensure subjects' anonymity, we masked all subject identifiers during the record review process. We reviewed the dental records of 3,071 potential subjects. To ensure a minimum follow-up of at least two years, we included in this analysis 2,780 subjects who had undergone at least two periodic examinations after the initial examination.

Dentists provide comprehensive forensic dental examinations for all U.S. Navy and Marine Corps recruits entering military service. These examinations include documentation of the status of all erupted, unerupted, missing and replaced teeth, as well as the type and condition of all existing restorations. Using bitewing, panoramic and any other necessary radiographs, dentists complete the patient's clinical examination by recording all soft- and hard-tissue findings, including dental caries and defective restorations, according to tooth number and surface, as well as by assessing the patient's risk status for dental caries, periodontal diseases and oral cancer.[18] All patients are required to undergo dental examinations at least once a year. Each periodic examination includes a clinical and radiographic assessment (new or existing radiographs, as indicated).

For all examinations, clinicians documented findings by using a standardized SOAP format[19] (that is, subjective findings [for example, patient's chief complaint, if any], objective findings [clinical and radiographic], assessment [interpretation of findings] and plan [a sequential treatment plan]). The objective component of the SOAP includes a listing of all tooth numbers and surfaces that require treatment because of caries or defective restorations; in addition, dentists use a standardized clinical charting format to graphically document tooth surfaces requiring treatment. The plan section lists and prioritizes all treatment needs.

Variables for analysis. We documented the following information from the dental records:

- date of entry into military service;
- number, type and location of dental restorations present at the initial examination;
- number, type and location of restorations documented as clinically acceptable at the initial examination;
- number, type and location of restorations documented as clinically unacceptable and requiring replacement at the initial examination;
- number, type and location of restorations documented as clinically acceptable at the initial examination, but requiring replacement at a subsequent examination;
- dates of diagnosing the need for restoration replacement;
- surfaces planned for treatment for each tooth that had a restoration requiring replacement.

For this study, we evaluated only posterior teeth (not third molars) with amalgam or resin-based composite restorations present at the initial examination. We excluded teeth that had been restored with more than one material. We documented restorations according to both tooth number and surface and divided them into two categories: one-surface occlusal restorations and multisurface restorations. We did not include in the analysis restorations that did not include the occlusal surface.

We classified existing restorations as clinically acceptable or requiring replacement; we included glass ionomer restorations, which frequently are difficult to distinguish from resin-based composite restorations, with the resin-based composite restorations. We defined restoration replacement as planned re-treatment documented during the initial or any periodic examination. The need for replacements could be the result of new primary caries, secondary caries or defective restorations or of endodontic therapy. We did not consider teeth with incipient caries (noncavitated lesions that extend less than 0.5 millimeters into dentin) to require replacement (according to the U.S. Navy Dental Corps Oral Disease Risk Management [ODRM] protocol,[18] these teeth should be treated with remineralization therapy rather than restorations).

In addition, we identified all restorations for which the replacement involved only the previously restored surfaces. Replacement of existing restorations (RERs) did not include replacements due to primary caries on previously nonrestored surfaces. We defined caries risk status (Table 1) according to the ODRM protocol,[18] with the exception that we did not include cervical decalcifications (white spot lesions) and interproximal incipiencies in our determination of risk.

We reviewed each subject's annual examination

TABLE 1

U.S. Navy Dental Corps Caries Risk Assessment Criteria.*

CARIES RISK STATUS	CRITERIA
Low	No cavitated or active carious lesions; no incipient occlusal or interproximal lesions; fewer than four cervical decalcifications or white spot lesions
Moderate	One to three cavitated or active carious lesions; one or more incipient occlusal or interproximal lesions; four or more cervical decalcifications or white spot lesions
High	Four or more cavitated or active carious lesions

* Adapted from Chief, Navy Dental Corps.[18]

findings to determine which restorations had been designated for replacement after the initial examination. We defined the date of replacement as the date of the dental examination at which the need for re-treatment had been documented; the time to replacement was the number of days from the initial examination to the examination documenting the need for replacement.

The institutional review board of NIDBR reviewed and approved our research protocol.

STATISTICAL ANALYSIS

We calculated the numbers of amalgam and resin-based composite restorations present at the subject's initial examination, as well as the number requiring replacement. We excluded from further analysis those restorations requiring replacement. Thus, we included in our analyses of restoration replacement during follow-up only those restorations judged to be clinically acceptable at the initial examination. We described the relative risk of replacement of initially clinically acceptable restorations by using adjusted hazard ratios (HRs) (that is, comparison of risk of replacement for resin-based composite with that for amalgam, a computerized calculation that takes into consideration the time to replacement, as well as the number of possible restorations at risk in each patient) to estimate differences in required re-treatment, while allowing for control of covariates.

We conducted further analyses to evaluate RERs (that is, replacements that included only the surfaces that had been restored previously). We propose that these restorations most likely failed because of material deterioration or recurrent caries. We excluded from our analyses all teeth for which surfaces requiring treatment were not documented. We included restorations for which replacement involved previously nonrestored surfaces with teeth not requiring replacement. We presumed that these restorations most likely were the result of new caries on the previously nonrestored surfaces, rather than restoration failure per se.

We used statistical software programs (SAS version 9.1, SAS Institute, Cary, N.C., and EpiInfo, version 3.2.2, U.S. Centers for Disease Control and Prevention, Atlanta) for all data analyses, setting all α levels of error at .05 and all confidence intervals at the 95 percent level.

RESULTS

We reviewed the dental records of 2,780 U.S. Navy (cohort 1 = 1,078) and Marine Corps (cohort 2 = 1,053; cohort 3 = 649) recruits. The mean age of subjects in each cohort was 20 years; more than 85 percent were male. The mean follow-up was 3.0 years (cohort 1, 3.4 years; cohort 2, 3.1 years; cohort 3, 2.3 years).

Table 2 shows the caries risk categories and number of amalgam and resin-based composite restorations for each cohort at the initial dental examination. The number of amalgam restorations exceeded that of resin-based composites in each cohort. However, the proportion of resin-based composite restorations increased from 10 percent in cohort 1 to 15 percent in cohort 2 to 25 percent in cohort 3. The majority of restorations involved only occlusal surfaces.

At the initial examination, dentists identified 964 (15.2 percent) of the 6,341 amalgam restorations and 199 (17.4 percent) of the 1,140 resin-based composite restorations as needing replacement. They found greater percentages of multisurface restorations requiring replacement for both materials (amalgam: one-surface, 13.5 percent and multisurface, 17.9 percent; resin-based composite: one-surface, 14.4 percent and multisurface, 25.4 percent). Table 3 shows the number and percentage of restorations that dentists judged to be clinically acceptable at the initial examination, but that they determined were in need of replacement during the follow-up period.

We documented each tooth surface requiring replacement for 696 amalgam replacements (306 RERs requiring replacement of the existing restoration only and 390 replacements that included at

least one previously nonrestored surface) and 141 resin-based composite replacements (79 RERs and 62 replacements that included at least one previously nonrestored surface). We considered 62 (44 percent) of 141 resin-based composite replacements and 390 (56 percent) of 696 amalgam replacements to be due to new primary caries. (We could not determine the surfaces that needed to be replaced for 70 amalgam and 16 resin-based composite restorations.) Table 4 presents the RERs (that is, replacement of existing restorations only; replacements due to primary caries on adjacent surfaces were considered nonreplacements): 306 (5.8 percent) of 5,307 amalgam restorations and 79 (8.5 percent) of 925 resin-based composite restorations.

TABLE 2

Subjects and restored teeth, by caries risk status, restorative material, surfaces restored and tooth type at initial dental examination.

VARIABLE	COHORT 1 1997 (n = 1,078)	COHORT 2 1999–2000 (n = 1,053)	COHORT 3 2002–2005 (n = 649)	TOTAL (N = 2,780)
Number (%) of Subjects, by Caries Risk Status				
Low	473 (44)	439 (42)	265 (41)	1,177 (42)
Moderate	371 (34)	396 (38)	261 (40)	1,028 (37)
High	234 (22)	218 (21)	123 (19)	575 (21)
Number (%) of Restored Teeth, by Subjects' Caries Risk Status				
Low	1,029 (36)	996 (34)	525 (31)	2,550 (34)
Moderate	1,123 (39)	1,215 (42)	769 (46)	3,107 (42)
High	744 (26)	684 (24)	396 (23)	1,824 (24)
TOTAL	**2,896**	**2,895**	**1,690**	**7,481**
Number (%) of Restored Teeth, by Restorative Material				
Resin-based composite	279 (10)	437 (15)	424 (25)	1,140 (15)
Amalgam	2,617 (90)	2,458 (85)	1,266 (75)	6,341 (85)
TOTAL	**2,896**	**2,895**	**1,690**	**7,481**
Number (%) of Restored Teeth, by Surfaces	**Occlusal**		**Multisurface**	
Resin-based composite	821 (72)		319 (28)	
Amalgam	3,868 (61)		2,473 (39)	
Number (%) of Restored Teeth, by Tooth Type	**Molars**		**Premolars**	
Resin-based composite	940 (82)		200 (18)	
Amalgam	5,322 (84)		1,019 (16)	

To control for potential confounders, we calculated HRs adjusted for five variables:

- material (resin-based composite versus amalgam);
- caries risk status (low, moderate, high);
- tooth type (premolar, molar);
- cohort (1, 2 or 3);
- restoration surfaces (multisurface versus one-surface).

TABLE 3

Resin-based composite and amalgam restorations requiring replacement for all reasons during follow-up.

RESTORATION TYPE	RESIN-BASED COMPOSITE (n = 941)			AMALGAM (n = 5,377)		
	Replacement		% Requiring Replacement	Replacement		% Requiring Replacement
	Yes	No		Yes	No	
All Restorations	157	784	16.7	766	4,611	14.2
One-Surface	107	596	15.2	419	2,917	12.6
Multisurface	50	188	21.0	347	1,694	17.0

Adjusted HRs (incorporating all five variables) revealed a significantly higher rate of replacement for resin-based composite than for amalgam restorations (adjusted HR, 1.28; $P < .05$). Furthermore, when we evaluated RERs, resin-based composites exhibited a significantly higher rate of replacement compared with that for amalgam (adjusted HR, 1.64; $P < .01$). Table 5 presents the adjusted HRs, comparing replacement rates for resin-based composite restorations with those for amalgam restorations for all replacements and for RERs.

For both restoration categories in Table 5, the greater the patient's caries risk, the greater the risk of restoration re-treatment. High-caries-risk subjects had more than twice the risk of re-treatment than did low-caries-risk subjects when we considered all replacements (adjusted HR, 2.04; $P < .01$, as well as a 50 percent higher risk of replacement of previously restored surfaces (RERs) (adjusted HR, 1.48; $P < .01$). Replacement rates for multisurface restorations also were greater than rates for one-surface restorations (replacement resulting

TABLE 4

Resin-based composite and amalgam restorations requiring replacement of surfaces during follow-up.

RESTORATION TYPE	RESIN-BASED COMPOSITE (n = 925)			AMALGAM (n = 5,307)		
	Replacement		% Requiring Replacement	Replacement		% Requiring Replacement
	Yes*	No†		Yes*	No†	
All Restorations	79	846	8.5	306	5,001	5.8
One Surface	47	645	6.8	150	3,147	4.5
Multisurface	32	201	13.7	156	1,854	7.8

* Replacement due to secondary caries or other factors limited to only the previously restored surfaces.
† Restorations not requiring replacement or restorations in teeth with new caries on previously nonrestored surfaces.

TABLE 5

Adjusted hazard ratios (HRs) comparing replacement rates for resin-based composite and amalgam restorations during follow-up.

VARIABLE	ADJUSTED HR FOR REPLACEMENT DUE TO ALL CAUSES*	ADJUSTED HR FOR REPLACEMENT OF EXISTING RESTORATION*†
Resin-Based Composite Versus Amalgam	1.28‡	1.64§
Moderate Caries Risk Versus Low Risk	1.45§	1.34¶
High Caries Risk Versus Low Risk	2.04§	1.48§
Molar Versus Premolar	1.26‡	1.27¶
Cohort 2 Versus Cohort 1	1.70§	1.41‡
Cohort 3 Versus Cohort 1	1.91§	2.11§
Multisurface Versus One Surface	1.39§	1.82§

* Full model: material, caries risk, tooth type, cohort, restoration surfaces.
† Replacement for reasons other than new caries on previously nonrestored surfaces.
‡ $P < .05$.
§ $P < .01$.
¶ $P > .05$.

from all causes: adjusted HR, 1.39; $P < .01$; RER-adjusted HR, 1.82; $P < .01$).

DISCUSSION

Although many large observational studies comparing amalgam and resin-based composite restorations in adults have been reported, the majority have evaluated restorations in European subjects.[3,5,6,10,11,13,14] Our study presents data gathered from dental records of healthy military men and women recruited from all 50 states, the District of Columbia and U.S. territories. The dental restorations in these recruits at their initial examination had been placed by a large number of private dentists with differing skills and opinions concerning the use of resin-based composite and amalgam in stress-bearing restorations.[2]

Studies. One of the studies comparing restorative materials in U.S. subjects was of children aged 6 to 10 years,[4] and the other two were published many years ago (in 1989[8] and 1990[12]). Moffa[8] reported the results of a long-term study of a number of resin-based composite and amalgam formulations, but only two dentists placed all of the restorations. Although restricting the number of providers in a study may improve the internal validity of that study, the skills of the participating dentists may not be representative of the skills of other dentists. Thus, the results may not be generalizable to a larger population of noncalibrated providers. Norman and colleagues[12] evaluated one resin-based composite in a relatively small sample of adults who were about 30 years of age. Again, such results may not be generalizable to other types of resin-based composite restorations or to patient populations exhibiting different characteristics.

We believe that our study evaluated a diverse range of restorative materials in a large sample of patients who are representative of young, healthy U.S. adults. Furthermore, we suggest that our findings are relevant to private practice settings because our new recruits' entrance into the military health care system is analogous to the acceptance of new patients into a private practice. In accepting a new patient, the provider cannot know precisely the age of his or her existing restorations; however, the provider assumes responsibility for the maintenance, and eventual replacement, of those restorations.

We believe it is reasonable for the practitioner, as well as the patient, to expect that a certain proportion of restorations—perhaps 15 to 17 percent, as found in our study—may require replacement on initial examination, and that others will

require replacement at subsequent examinations. Additional studies are needed to delineate possible trends in restoration replacement among patients transferring from one provider to another.

Criteria for replacement. The overarching criteria for determining the need for restoration replacement in the U.S. Navy health care setting are the presence of acute or chronic symptoms and restoration defects (such as fractures, overhangs, open margins), fractures of remaining tooth structure and/or recurrent caries that, in the examiner's judgment, are likely to cause symptoms or tissue damage within 12 months.[20] All dentists (both military and civilian) credentialed in U.S. Navy treatment facilities receive diagnostic standardization training when they are appointed to the staff; recalibration is required annually at all facilities. At most facilities, this training is administered by senior-ranking providers with postdoctoral degrees in oral medicine/oral diagnosis or operative dentistry. At the Naval Health Clinic Great Lakes (site of the Navy's only in-processing center where all U.S. Navy recruits receive initial dental examinations), all providers (predominantly civilian dentists and assistants) who perform in-processing examinations participate in monthly calibration exercises.

Owing to the retrospective nature of the study, we were unable to evaluate the interexaminer or intraexaminer reliability of diagnoses for restoration replacement. Although we are aware of no published reports comparing restoration replacement rates among civilian and military settings, we suggest that the above diagnostic criteria are both conservative and applied reasonably consistently in U.S. Navy settings. There is, of course, the possibility of individual deviation and overtreatment. However, the military offers no incentive to replace restorations. Rather, the inherent peer review, as well as the overwhelming volume of treatment need in the military environment, tends to foster a conservative approach to restorative treatment planning.

Our data show that dental amalgam remains the predominant material in use, accounting for more than 75 percent of all posterior restorations among new recruits. We found resin-based composite restorations in fewer than 25 percent of the restored posterior teeth in our subjects. However, the ratio of amalgam to resin-based composite decreased from 10:1 for cohort 1 (reporting for duty in 1997) to 6:1 for cohort 2 (reporting in 1999-2000) and to 3:1 for cohort 3 (reporting after September 2002). This trend is consistent with other reports of the changing profile of restorative care, as civilian dentists and patients opt for resin-based composite over amalgam.[21-23] These data suggest that the proportion of resin-based composite restorations is likely to continue to increase.

Our results indicate that a total of 356 (31.2 percent) of 1,140 resin-based composite restorations required replacement (18 percent at the initial examination and 17 percent during the follow-up period), while 1,730 (27.3 percent) of 6,341 amalgam restorations required replacement (15 percent at the initial examination and 14 percent during the follow-up period). When we included all reasons for replacement and controlled for confounding factors, we found statistically higher (adjusted HR, 1.28; $P < .05$) replacement rates for resin-based composite restorations compared with those for amalgam restorations during the observation period. This finding is consistent with those of previous studies of resin-based composite and amalgam restorations.[3,5,6,8]

The use of resin-based composites was more prevalent in restorations with fewer surfaces.

We also observed a greater risk of need for replacement for multisurface restorations than for one-surface restorations. This finding agrees with those from other studies in which larger restorations, in general, exhibited higher annual failure rates than did smaller restorations.[4,5] We noted that the use of resin-based composites was more prevalent in restorations with fewer surfaces (one-surface resin-based composite restorations, 72 percent; one-surface amalgam restorations, 61 percent), which suggests that dentists may have decided to limit the size of resin-based composite restorations. Limiting the use of resin-based composites to smaller cavity preparations, combined with recent improvements in material properties, may explain the smaller (although statistically significant) disparities in replacement rates observed in our study compared with those in previous studies.[3,5]

Study limitations. One possible limitation of our study is the inability to determine the time of placement of the initial restorations, because all were placed before the subjects reported for active

duty. As a result, we were unable to calculate restoration longevity from our data. However, given that the mean age of subjects was 20 years, the oldest restorations (placed on first permanent molars) probably were no older than 12 to 14 years. Although this may seem to be an acceptable service life,[24] it likely applies to a minority of the restorations in this study. Restorations in second molars and premolars would be considerably newer (less than eight to 10 years old). Moreover, anecdotal evidence suggests that many recruits seek dental care from civilian providers during the weeks or months preceding enlistment. If this is true, many of the restorations replaced during the first years of military service were less than four to five years old and, thus, did not meet the median life spans expected for amalgam (eight to 11 years) and resin-based composite (six to nine years).[10,25]

Although further study is needed to delineate factors that may contribute to premature restoration failure, this study provides some evidence that restorations in molars require more re-treatment than do those in premolars. Furthermore, because of the previously described shifts in treatment patterns, there may be differences in the mean age of restorations as a function of material; most likely, amalgam restorations are older. This may adversely bias comparative longevity estimates for amalgam.

Another limitation of our study is that the data available from dental records did not allow us in all cases to determine the reasons for replacement. Restoration replacement may be due to material failure, tooth weakening or fracture, recurrent (secondary) caries or primary caries on adjacent surfaces.[5,10] According to Mjör and colleagues[10] and Mjör,[26] secondary caries is the most frequently cited reason for restoration failure in permanent teeth. However, the reasons for failure may differ for each restorative material. For example, resin-based composite may exhibit a greater risk of secondary caries compared with that for amalgam, but the materials may exhibit a similar risk of bulk material fracture[3] and cuspal fracture.[27]

Our findings suggest that a large proportion of restorations in this population were replaced as a result of primary caries (resin-based composite, 44 percent; amalgam, 56 percent), which may have diminished the effect of material failure and secondary caries rates. When we conducted analyses of RERs (for which we considered replacements due to primary caries to be nonfailures), we observed a higher replacement risk for resin-based composite than for amalgam restorations, which we believe was due to material failure or secondary caries. These findings may have been influenced by misclassification bias in that many replacements thought to be due to primary caries may have been caused by material failure or recurrent caries that had extended to nonrestored tooth surfaces. Further studies are needed to determine if material selection influenced the severity of restoration failures in this population.

The type and severity of restoration failure are influenced by several factors, including restoration size, number of surfaces, tooth type, position in the dental arch and the patient's age.[3,5,10,27] Our finding of a large proportion of replacements due to primary caries is similar to the results of a study by Soncini and colleagues,[4] who reported high replacement rates in children aged 6 to 10 years as a result of primary caries. The large percentage of restorations replaced because of primary caries reveals the need for an aggressive risk management and prevention program for this young population.

In 2005, Haj-Ali and colleagues[2] reported that 28.6 percent of dentists who did not use amalgam and 10.5 percent of dentists who used amalgam did not consider the patient's caries rate a significant factor in their choice of restorative materials. However, our study findings demonstrate that an increase in restoration re-treatment was associated with increasing caries risk status. This is consistent with other epidemiologic findings for this population. Compared with patients who were caries-free at entry into the U.S. Navy, personnel who had active caries—even after receiving complete restorative treatment—exhibited significantly higher rates of sealant failure (18 percent versus 8 percent),[28] required more restorations (1.9 versus 1.2)[29] and were twice as likely to experience a restorative or endodontically related dental emergency[30] during their first four years of military service.

Results of other studies[12-14] suggest that similar rates of replacement can be achieved for resin-based composite and amalgam restorations; our study results do not support these findings. The significantly higher risk of replacement for resin-based composites (replacement for all causes and for RERs) suggests that amalgam may be the more appropriate material

to use to restore posterior teeth in this young adult population.

CONCLUSIONS

Among these military recruits, dental amalgam remained, by a fivefold margin, the most predominant restorative material observed in posterior teeth. However, this proportion appears to be decreasing at a steady pace. At the initial examination, dentists judged as clinically unacceptable more than 15 percent of all existing posterior amalgam and resin-based composite restorations.

Across the observation period, an additional 15 percent of restorations required replacement. Multisurface restorations were more likely to require replacement than were single-surface restorations. We observed a higher risk of replacement for resin-based composite restorations than for amalgam restorations. Approximately one-half of all replacements were due to caries on previously noncarious surfaces. Subjects identified as being at high caries risk demonstrated significantly higher restoration replacement rates than did low-caries-risk subjects. Therefore, patients at a higher risk of developing caries may require more frequent dental care to ensure that new and recurrent carious lesions are prevented.

Moreover, although esthetic requirements, patient preference or both may favor the choice of resin-based composite, the added cost and time required for placement, as well as the potential increase in frequency of replacement, mandate that posterior resin-based composite restorations be limited to patients with low-to-moderate caries risk, be restricted to preparations of a size appropriate for the material and be placed with meticulous restorative technique and strict adherence to the manufacturer's instructions. ■

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