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A transition scoring system of caries increment with adjustment of reversals in longitudinal study: evaluation using primary tooth surface data

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Abstract – *Objectives:* The aim of this paper is to evaluate a new comprehensive scoring system for longitudinal studies using the International Caries Detection and Assessment System (ICDAS). *Methods:* A sample of 638 children were examined in 2002–2003 and again in 2007. Caries was assessed using the ICDAS criteria which assess six clinical stages of dental caries. Based on a transition matrix matching the baseline and follow-up ICDAS scores, we developed transition weights to best describe the progression, regression, or no progression nor regression of dental caries. Differential weights were assigned to transitions involved with noncavitated, cavitated, filled, crowned, or missing lesions. This method [transitional scoring system (TSS)] differentiated biologically plausible reversals from those because of examiner's misclassification. We computed and compared mean dmfs (decayed, missing, and filled tooth surfaces) increment scores including ($d_t$mfs) or excluding the noncavitated stage ($d_c$mfs) from TSS and another adjustment method proposed by Beck (modified Beck's method). The coefficients of variation (CV) of the two methods were also compared. *Results:* Mean $d_t$mfs from TSS was slightly higher than that from modified Beck's method. There was no difference in mean $d_c$mfs between two methods. The ratios of CV indicated that the CV of TSS was significantly smaller than those from modified Beck's method. *Conclusions:* There were differences in caries increment scores between the two methods when we accounted for the transition of noncavitated lesions. The evaluation of CV concluded that TSS was more efficient because it requires less sample size compared with the modified Beck's method to detect a treatment effect. Both methods can be used to compute caries increments for populations with similar distribution of the dmfs scores to the sample used in this study.

Key words: caries; caries increment; cohort studies; epidemiology; measurement

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Computing outcomes measures of dental caries in longitudinal studies in children is a complex process where both progression and regression of disease occur within a mouth in addition to the eruption, exfoliation, or extraction of primary teeth. To measure the transition of caries in longitudinal studies, previous studies have suggested the use of a symmetric matrix where all potential transitions at each tooth surface level were evaluated (1, 2). Specifically, all pairs of baseline and follow-up caries assessments were given predetermined weights, and the sum of the

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weights of tooth surfaces with progression of caries multiplied by the assigned weights resulted in a caries increment score for an individual (1, 2).

One complicating factor in longitudinal studies using ICDAS is that in addition to the nonclinically plausible 'reversals' (i.e., a cavitated lesion became sound surface), there are transitions of noncavitated carious lesions to sound, which may be considered either plausible or not depending on the stage of the caries process. This transition is not adjusted for when the net caries increment method (NCI) is used. The NCI is computed by subtracting reversals from new lesion that have developed during a follow-up period with the assumption that examiners randomly made an equal number of false-positive and false-negative errors at baseline and follow-up (3). However, simple removal of these errors is likely to introduce bias because false-positive and false-negative errors may not occur randomly. Further, reversals could be biologically plausible such as a noncavitated enamel lesion at baseline examination recorded as a sound tooth surface at follow-up. When noncavitated carious stages are measured, the assumption that all reversals are because of examiner errors becomes invalid. Removing of 'reversals' could result in overcorrection of errors and therefore underestimation of caries progression.

Addressing this problem, Beck et al. (3) proposed to adjust caries increment by proportion of reversals instead of actual number of reversals. They argued that the assumption for NCI could be easily violated because examiner's misclassification errors were not random in many clinical situations and proposed to adjust caries increment by proportion of reversals instead of actual numbers of reversals. This prevalence-based adjustment method (adjusted caries increment or ADJCI) was based on the assumption that examiners' misclassification errors were positively associated with prevalence of dental caries. However, ADJCI, like NCI, considered the number of reversals as an estimate of examiner misclassification, which could not hold true when noncavitated lesions were included as dental caries outcomes; some reversals occurred as a result of biologic remineralization (2).

In this paper, we present and evaluate a new scoring system that incorporates transition of noncavitated lesions and reversals at the tooth surface level.

Materials and methods

Study population

Data for this study were obtained from the Detroit Dental Health Project, a longitudinal cohort study focusing on the oral health of low-income African–American children and their caregivers. This study protocol was approved by the Institutional Review Board for Health Sciences at the University of Michigan, and the caregivers of all participants gave written consent for inclusion in this study.

The sampling design consisted of a stratified two-stage area probability sample of households from the 39 census tracts with the highest proportion of low-income residents in the city of Detroit. Power calculations indicated that a sample of 1000 eligible children completing examinations would meet precision requirements for the project. To be eligible for the study, households needed to comprise a child ages zero to 5 years and his/her main caregiver. Among 1386 eligible families, 1021 dyads of child and caregiver came to a central facility in Detroit to complete dental examinations in 2002–2003 (W1; response rate = 74.0%). Along with this clinical examination, face-to-face interviews were administered by trained interviewers to collect the information on sociodemographic and oral health–related behavioral characteristics of the participants, as well as their general health histories. Details of the sampling and data collection procedures have been described in previous reports (4, 5). Baseline participants were followed up in 2004–2005 (W2) and in 2007 (W3), and among these, 77.0% (n = 790) and 64.1% (n = 654) returned to complete an interview and receive a clinical oral examination to W2 and W3 data collection, respectively. We examined whether there was systematic differences between caregivers and children who participated in follow-up and those who dropped out. There was no significant difference between the two groups in terms of dental caries and demographic characteristics. This study focused on 638 children whose primary tooth surfaces data were collected in both W1 and W3.

Dental caries assessment

Using a system proposed to the research team by Dr. Al Kingman (personal communication), we evaluated reliability of the classifications in W1 and W3 by analyzing not only the agreement decisions but also marginal homogeneity, agreement on numbers of tooth surfaces in the marginal columns, and graphical presentation of differences in classification. In W1, four dentists had good to excellent intra- and inter-reliability (Fleiss–Cohen kappa coefficients 0.61–1.00) (4). In W3, a new team of dentists (except for one examiner from W1) had an overall good reliability except for assessments of noncavitated lesions where there were differences among the examiners.

The numbers of tooth surfaces were counted for the sampled child using the following categories: sound tooth surfaces (s: ICDAS 00, 10, 20), noncavitated lesions (d_{nc}: ICDAS 01, 11, 12, 21, 22), cavitated lesions (d_c: ICDAS 03–06, 13–16, 23–26), filled lesions (f: ICDAS 30, 40, 70, 80), filled/noncavitated lesions (fd_{nc}: ICDAS 31, 32, 41, 42, 71, 72, 81, 82), filled/cavitated lesions (fd_c: ICDAS 33–36, 43–46, 73–76, 83–86), crowned surfaces (c: ICDAS 50, 60), crowned/noncavitated lesions (cd_{nc}: ICDAS 51, 52, 61, 62), crowned/cavitated lesions (cd_c: 53–56, 63–66), missing tooth surfaces because of caries (m: ICDAS 97), and missing because of other reasons than caries (mo: ICDAS 98). Unerupted teeth (u: ICDAS 99) and not-examined (or excluded) tooth surfaces (x: ICDAS 96) were also counted. This caries assessment was performed for each of W1, W2, and W3 dental data. This study focused on W1 and W3 data.

Transition scoring system (TSS)

We first created a transition matrix by cross-tabulating the baseline caries assessment (W1) with the subsequent assessment (W3). From this transition matrix, we examined each of all potential transition pairs and developed a pair-specific weight to best describe incidence of dental caries in a surface level. Summation of surface-level weights in an individual level resulted in adjusted increment scores of dmfs score (decayed, missing, and filled tooth surfaces) including $d_t$mfs and $d_c$mfs, where d_t stands for decay in 'total' including both noncavitated and cavitated stage, and d_c stands for decay in 'cavitated only' excluding the noncavitated stages. The general scoring scheme for $d_t$mfs, as summarized below as well as in Table 1, was laid out to capture complex transitions of dental caries, such as transition from/to noncavitated, crowned, or missing lesions because of caries (transition scoring system or TSS). In this system, we also differentiated biologically plausible reversals (i.e., because of remineralization and examiner misclassification) from biologically implausible reversals (only because of examiner misclassification).

- No progression nor regression
  - No change in the caries status between W1 and W3 caries assessment received a score of 0.
  - Transition from d_c or fd_c: we assumed that there was no further progression of disease from the baseline cavitated lesions. Except reversals, transition from d_c or fd_c received a score of 0.
  - Transition from filled (f, fd_{nc}, fd_c) to crowned surfaces (c).
  - Transition from cd_c to d_c, c, or m.
  - Transition from missing tooth surfaces (m, mo, x) received a score of 0 regardless of the subsequent caries assessment.
- Progression (score 1)
  - Transition from sound or d_{nc}: all progression cases were given score 1 except transition to c or m.
  - Transition from f to fd_{nc}, fd_c, cd_{nc}, or cd_c.
  - Transition from fd_{nc} to d_c, fd_c, or cd_c.
  - Transition from c: crowned surface was treated as sound. Thus, transition to noncavitated lesions (d_{nc}, fd_{nc}, cd_{nc}) or cavitated lesions (d_c, fd_c, cd_c) was assigned a score of 1.
  - Transition from cd_{nc}: similar to fd_{nc}, transition to d_c, fd_c, or cd_c was assigned a score of 1.
  - Transition from cd_c to filled surface (f).
  - Transition from u: unerupted teeth at W1 was considered as sound. Thus, transition from u received scores identical with that from sound surfaces.
- Progression
  - Transition from sound or d_{nc}: progression to c or m was assigned a score of 0.5 to avoid the overestimation of the disease (i.e., not all missing or crowned) tooth surfaces were previously carious.
- Biologically plausible regression (score = 1)
  - Transition from d_{nc} to sound.
- Biologically implausible regression (score = 1)
  - Transition from d_c to sound, d_{nc} or cd_{nc}.
  - Transition from f to sound or d_{nc}.
  - Transition from fd_{nc} to sound or f.
  - Transition from fd_c to sound, f, or noncavitated lesions (d_{nc}, fd_{nc}, cd_{nc}).
  - Transition from c to sound.
  - Transition from cd_{nc} to sound, f, or c.
  - Transition from cd_c to sound, noncavitated lesions (d_{nc}, fd_{nc}, cd_{nc}), or crowned surfaces (c).

The same weight schemes and rationales were applied to the increment score of $d_c$mfs. A key difference between the $d_t$mfs and the $d_c$mfs scoring

Table 1. Weighing scheme for caries increment scoring in transition scoring system (TSS)

$d_t$mfs

		W3											
		s	d_{nc}	d_c	f	fd_{nc}	fd_c	c	cd_{nc}	cd_c	m	mo	x
W1	s (u)[a]	0	1	1	1	1	1	0.5	1	1	0.5	0	0
	d_{nc}	−1	0	1	1	1	1	0.5	0	1	0.5	0	0
	d_c	−1	−1	0	0	0	0	0	−1	0	0	0	0
	f	−1	−1	0	0	1	1	0	1	1	0	0	0
	fd_{nc}	−1	0	1	−1	0	1	0	0	1	0	0	0
	fd_c	−1	−1	0	−1	−1	0	0	−1	0	0	0	0
	c	−1	1	1	0	1	1	0	1	1	0	0	0
	cd_{nc}	−1	0	1	−1	0	1	−1	0	1	0	0	0
	cd_c	−1	−1	0	1	−1	0	−1	−1	0	0	0	0
	m	0	0	0	0	0	0	0	0	0	0	0	0
	mo	0	0	0	0	0	0	0	0	0	0	0	0
	x	0	0	0	0	0	0	0	0	0	0	0	0

$d_c$mfs

		W3								
		s+d_{nc}	d_c	f+fd_{nc}	fd_c	c+cd_{nc}	cd_c	m	mo	x
W1	s (u)[a]+d_{nc}	0	1	1	1	0.5	1	0.5	0	0
	d_c	−1	0	0	0	0	0	0	0	0
	f+fd_{nc}	−1	0	0	1	0	1	0	0	0
	fd_c	−1	0	−1	0	0	0	0	0	0
	c+cd_{nc}	−1	1	0	1	0	1	0	0	0
	cd_c	−1	0	1	0	−1	0	0	0	0
	m	0	0	0	0	0	0	0	0	0
	mo	0	0	0	0	0	0	0	0	0
	x	0	0	0	0	0	0	0	0	0

Yellow: diagonal calls where the caries status was the same in both W1 and W3, green: symmetric calls where different weights were used.

s, sound tooth surface (ICDAS 00, 10, 20); d_{nc}, noncavitated lesions (ICDAS 01, 11, 12, 21, 22); d_c, cavitated lesions (ICDAS 13–16, 23–26); f, filled lesions (ICDAS 30, 40, 70, 80); fd_{nc}, filled/noncavitated lesions (ICDAS 31, 32, 41, 42, 71, 72, 81, 82); fd_c, filled/cavitated lesions (ICDAS 33–36, 43–46, 73–76, 83–86); c, crowned surfaces (ICDAS 50, 60); cd_{nc}, crowned/noncavitated lesions (ICDAS 51, 52, 61, 62); cd_c, crowned/cavitated lesions (ICDAS 53–56, 63–66); m, missing tooth surfaces because of caries (ICDAS 97); mo, missing tooth surfaces because of other reasons than caries (ICDAS 98); u, unerupted teeth (ICDAS 99); x, not-examined (or excluded) tooth surfaces (ICDAS 96); $d_t$mfs, decayed, missing, and filled surfaces; $d_c$mfs, decayed, missing, and filled surfaces excluding the noncavitated stage.

[a]Unerupted teeth at W1 were assumed to be sound.

systems, however, was that noncavitated lesions were not uniquely identified in the $d_c$mfs scoring system. Instead, these were combined with disease-free surfaces, resulting in creating sound+d_{nc}, f+fd_{nc}, and c+cd_{nc}.

Modified Beck's method

For a comparison method, we used the prevalence-based caries increment formula that Beck and his colleagues proposed (3). To account for examiners' misclassification errors, they adjusted caries increment for the proportion of baseline dental caries (adjusted caries increment or ADJCI). However, the original formula was developed to measure increment of only cavitated or filled surfaces. To make estimated caries increment from ADJCI comparable with those from TSS, we modified ADJCI to incorporate noncavitated and missing surfaces (modified Beck's method). In this method, we evaluated each of transition cases associated with noncavitated, cavitated, filled, or missing surfaces (Table 2). Applying counts of surfaces with progression, regression, or no progression nor regression to the formula, we computed adjusted caries increment score in a child level.

Table 2. Application of Beck's formula to compute increment of $d_t$mfs and $d_c$mfs (modified Beck's method)

	Progression		Regression		No progression nor regression	
	W1	W3	W1	W3	W1	W3
$d_t$mfs	s[a]	d_{nc}, fd_{nc}, cd_{nc}	d_{nc}, fd_{nc}, cd_{nc}	s	d_{nc}, fd_{nc}, cd_{nc}	d_{nc}, fd_{nc}, cd_{nc}
	s[a]	d_c, fd_c, cd_c	d_c, fd_c, cd_c	s	d_{nc}, fd_{nc}, cd_{nc}	f, c
	s[a]	f, c	d_c, fd_c, cd_c	d_{nc}, fd_{nc}, cd_{nc}	d_c, fd_c, cd_c	d_c, fd_c, cd_c
	d_{nc}, fd_{nc}, cd_{nc}	d_c, fd_c, cd_c	f, c	s	d_c, fd_c, cd_c	f, c
	s[a], d_{nc}, d_c, f, fd_{nc}, fd_c, c, cd_{nc}, cd_c	m			f, c	f, c
					f, c	d_{nc}, fd_{nc}, cd_{nc}
					f, c	d_c, fd_c, cd_c
					m	m
$d_c$mfs	s[a]	d_2, fd_2, cd_2	d_c, fd_c, cd_c	s	d_c, fd_c, cd_c	d_c, fd_c, cd_c
	s[a]	f, c	d_c, fd_c, cd_c	d_{nc}	d_c, fd_c, cd_c	f, c
	s[a]	fd_1, cd_1	f, c	s	f, c	f, c
	d_{nc}, fd_{nc}, cd_{nc}	d_2, fd_2, cd_2	fd_{nc}, cd_{nc}	s	f, c	fd_{nc}, cd_{nc}
					f, c	d_c, fd_c, cd_c
					fd_{nc}, cd_{nc}	f, c
	s[a], d_{nc}, d_c, f, fd_{nc}, fd_c, c, cd_{nc}, cd_c	m			m	m

Adjusted increment = progression × [no progression nor regression/(regression + no progression nor regression)].
s, sound tooth surface (ICDAS 00, 10, 20); d_{nc}, noncavitated lesions (ICDAS 01, 11, 12, 21, 22); d_c, cavitated lesions (ICDAS 13–16, 23–26); f, filled lesions (ICDAS 30, 40, 70, 80); fd_{nc}, filled/noncavitated lesions (ICDAS 31, 32, 41, 42, 71, 72, 81, 82); fd_c, filled/cavitated lesions (ICDAS 33–36, 43–46, 73–76, 83–86); c, crowned surfaces (ICDAS 50, 60); cd_{nc}, crowned/noncavitated lesions (ICDAS 51, 52, 61, 62); cd_c, crowned/cavitated lesions (ICDAS 53–56, 63–66); m, missing tooth surfaces because of caries (ICDAS 97); mo, missing tooth surfaces because of other reasons than caries (ICDAS 98); u, unerupted teeth (ICDAS 99); x, not-examined (or excluded) tooth surfaces (ICDAS 96); $d_t$mfs, decayed, missing, and filled surfaces; $d_c$mfs, decayed, missing, and filled surfaces excluding the noncavitated stage.
[a]Unerupted teeth at W1 were assumed to be sound.

Statistical analysis

Variability of the primary outcome measure and the sample size determines statistical power. This implies that given the fixed sample size, variability can be used as an indicator of efficiency and sensitivity of a statistical test based on that particular measure (6). Variability is often reported as coefficient of variance (CV). CV, the standard deviation (SD) divided by the mean, describes a within-subject variation as their average score, and the ratio of CV is proportional to the ratio of sample size requirement (7, 8). Thus, a smaller CV can be translated into smaller variability and a smaller sample size required to achieve a desirable statistical power.

Descriptive statistics was computed to illustrate caries transition between W1 and W3 in a tooth

Table 3. Row percent (%) of transition of W1 dental caries over 4 years (W3) among sampled African–American children in Detroit

W1	W3 caries status												
Caries status	*N*	s	d_{nc}	d_c	f	fd_{nc}	fd_c	c	cd_{nc}	cd_c	m	mo	x
s (u)[a]	42 153	87.2	5.4	3.9	1.0	0.6	0.2	0.8	0	0	0.1	0.4	0.4
d_{nc}	992	24.7	33.9	20.5	8.4	7.4	1.7	1.5	0	0	0.1	1.9	0
d_c	489	13.3	5.7	46.0	9.8	9.8	6.5	5.7	0	0	2.0	1.0	0
f	70	22.9	4.3	8.6	28.6	31.4	4.3	0	0	0	0	0	0
fd_{nc}	12	0	0	16.7	8.3	58.3	16.7	0	0	0	0	0	0
fd_c	4	25.0	0	0	0	0	75.0	0	0	0	0	0	0
c	15	33.3	0	0	0	0	0	66.7	0	0	0	0	0
cd_{nc}	0	0	0	0	0	0	0	0	0	0	0	0	0
cd_c	0	0	0	0	0	0	0	0	0	0	0	0	0
m	20	20.0	0	5.0	0	0	0	0	0	0	75.0	0	0
mo	0	0	0	0	0	0	0	0	0	0	0	0	0
x	200	84.0	9.5	3.5	2.0	1.0	0	0	0	0	0	0	0

[a]Unerupted teeth at W1 were assumed to be sound.

surface level as well as in a child level. Cross-tabulation between W1 and W3 assessment was performed, and adjusted caries increment was computed using two adjustment methods. Then, we computed CV to evaluate the variability of both methods. One thousand replications of the original data (n = 638) were randomly generated on a uniform distribution with replacement using SAS 9.1 software (9, 10). Estimates of the 95% confidence intervals of CV were obtained from these bootstrapped data. All statistical analyses were conducted using SAS 9.1 software (10).

Results

Table 3 presents transition of dental caries at the tooth surface level. Over 95% of W1 tooth surfaces were either sound or unerupted. Of these, 87.2% remained sound while 9.3% progressed to d_{nc} or d_c lesions in 4 years. A majority of baseline noncavitated lesions (d_{nc}) remained noncavitated (33.9%) or progressed to a more severe caries (d_c: 20.5%, m: 0.1%). Similarly, 46% of baseline-cavitated lesions (d_c) remained cavitated, and 2% progressed to tooth loss as a result of caries. During the same period, only a small proportion of W1 d_{nc} and d_c lesions were treated with fillings and crowns (d_{nc}: 10%, d_c: 16%).

Using TSS and the modified Beck's method, we weighted each pair of surface-level transition and summarized weights into individual-level caries increment scores ($d_t$mfs and $d_c$mfs). Table 4 shows that mean increment of $d_t$mfs from TSS (7.66) was slightly higher than that from the modified Beck's method (7.30), and this difference was statistically significant (P = 0.002). Mean increment of $d_c$mfs from TSS (4.45) was not statistically different from that of the modified Beck's method (4.44). An overall similar but slightly inconsistent pattern between the two methods was found when caries increment comparison was stratified by children's baseline characteristics including children's brushing frequency and dental visit. For example, among those with brushing frequency greater than 7 times per week or dental visits, the mean increment of $d_t$mfs from TSS was higher than that from the modified Beck's method, whereas there was no significant difference in mean increment of $d_c$mfs between the two methods. On the other hand, mean increment of $d_t$mfs or $d_c$mfs from the two methods was not significantly different among those with the brushing frequency less than 7 times per week or no dental visits.

Table 5 shows that the estimated CV of $d_t$mfs from TSS and the modified Beck's method were 1.08 and 1.16, respectively. The ratio of CV of TSS to the modified Beck's method was 0.93 (95% CI:

Table 4. Mean caries increment (SD) using transition scoring system and modified Beck's method among sampled African–American children in Detroit

	Transition scoring system (TSS)	Modified Beck's method	
	Mean (SD)	Mean (SD)	P-values[a]
$d_t$mfs			
Overall	7.66 (8.30)	7.30 (8.50)	0.002
Brushing teeth <7 times per week	9.25 (9.23)	9.05 (9.61)	0.267
Brushing teeth ≥7 times per week	6.79 (7.62)	6.34 (7.67)	0.002
No dental visit	8.55 (8.84)	8.38 (9.22)	0.184
Dental visit	5.95 (6.84)	5.21 (6.41)	0.001
$d_c$mfs			
Overall	4.45 (6.75)	4.44 (7.24)	0.944
Brushing teeth <7 times per week	5.42 (7.61)	5.39 (8.13)	0.831
Brushing teeth ≥7 times per week	3.91 (6.18)	3.92 (6.65)	0.936
No dental visit	4.88 (7.37)	5.00 (8.04)	0.235
Dental visit	3.60 (5.28)	3.35 (5.19)	0.109

$d_t$mfs, decayed, missing, and filled surfaces including both the noncavitated and cavitated stage; $d_c$mfs, decayed, missing, and filled surfaces excluding the noncavitated stage.
There was significant difference in caries increment between children who were reported to brush their teeth less than 7 times per week and those who were reported to brush their teeth greater than 7 times per week at W1. Likewise, mean caries increment among children who had dental visits at W1 was significantly different from that among children who reported not to have dental visits at W1.
[a]Calculated from paired t-test.

Table 5. Estimates of coefficients of variation (CV) of caries increment derived from transition scoring system (TSS) and modified Beck's method

	$d_t$mfs	$d_c$mfs
Estimates of CV (95% confidence interval)		
TSS	1.08 (0.99–1.17)	1.51 (1.39–1.66)
Modified Beck's method	1.16 (1.07–1.26)	1.62 (1.50–1.75)
Ratio of CV (95% confidence interval)		
TSS versus modified Beck's method	0.93 (0.89–0.97)	0.93 (0.89–0.98)

$d_t$mfs, decayed, missing, and filled surfaces including both the noncavitated and cavitated stage; $d_c$mfs, decayed, missing, and filled surfaces excluding the noncavitated stage.

0.89–0.97), indicating that the CV of TSS was significantly smaller than that of the modified Beck's method. The same pattern was found when the estimated CV of $d_c$mfs was compared.

Discussion

In this study, we developed TSS to estimate incidence of dental caries over time. Based on this transition matrix, we created weighting schemes to describe various stages of caries process and their longitudinal development including noncavitated and missing surfaces. In these weighting schemes, we also accounted for potential measurement errors from examiners to adjust for summary increment scores for biologically nonplausible reversals.

The mean $d_t$mfs score from TSS was slightly higher than that from modified Beck's method, but there was no statistical difference in mean $d_c$mfs score between two methods. The difference in $d_t$mfs score could be because of different weighting schemes that two methods used regarding noncavitated lesions. TSS examined all transition pairs from/to noncavitated lesions and implemented case-specific weights. This enabled us to measure caries initiation and caries progression separately, which could improve efficiency and sensitivity of caries increment scores (11). In contrast, modified Beck's method categorized them into progression, regression, and no progression nor regression and weighted them using three scores (e.g., 1 for progression, 0 for no progression nor regression, −1 for regression). This method was not able to differentiate biologic plausible reversals from non-plausible reversals of noncavitated lesions. As transition from d_{nc} to s is considered evidence of remineralization, the slightly lower mean $d_t$mfs score from modified Beck's method indicates that this could overestimate reversals, consequently underestimating caries increment (11). Given high prevalence of noncavitated lesions among very young children (12, 13), a differential weighting approach for noncavitated lesions is more appropriate to describe dynamic development of dental caries in young children.

Another area of difference between the two methods is the evaluation of missing surfaces because of caries. In modified Beck's method, we assigned a full weight (score 1) on missing surfaces, whereas we used half weight (score 0.5) in TSS. Given the similar result in mean $d_c$mfs scores between the two methods, this difference in weighting missing surfaces is likely to have little impact on the overall estimation of caries increment in our study population. However, the proportion of missing surfaces (m) in the sampled children was only 0.1% of total baseline surfaces; if the examined children had a high proportion of missing surfaces, the modified Beck's method is likely to produce a caries increment score greater than TSS. It is not clear whether the use of a full weight on missing surfaces could overestimate caries experience because previous studies (14, 15) evaluated DMF indexes to adjust the missing component only in the cross-sectional context. Additional studies are warranted to assess various weighting schemes to account for the missing component of the caries increment estimation.

We evaluated variability of the caries increment outcomes from two adjustment methods by comparing CV estimates. CV of TSS was significantly smaller than those of modified Beck's method, implying that our proposed method, relative to modified Beck's method, requires smaller sample size for the assessment of variability. As we described elsewhere, modified Beck's method categorized all transition pairs into three cases (progression, no progression nor regression, and regression) and assigned score 1, 0, and −1, respectively. We speculate that this simple weighing scheme could not properly control measurement errors, which might lead to decreasing the precision of the outcome.

This study used the longitudinal data of young children with high risk of dental caries to assess variability of two methods. Because incidence of dental caries greatly varies by different age groups, our findings may not be replicated if different population is evaluated. Future studies based on the population with various age groups are warranted to examine whether variability remains the same across all age groups. Another limitation is that we had disagreement between dentists in assessing W3 noncavitated lesions. Although our weighting scheme is strongly supported by clinical rationale, it should be noted that it is not a gold standard measure of caries increment. Further discussion among researchers should follow to establish the gold standard weighting scheme based on the ICDAS system.

The TSS method had a higher increment of $d_t$mfs scores over 4 years than the modified Beck's method. This difference could arise because the TSS used a differential weighting scheme on transition of noncavitated lesions. Estimated CV found that the TSS method is a more efficient method to achieve a desirable statistical power. Based on the findings, we conclude that both methods are equivalent in measuring caries increments provided that the incidence rates of the different components of the dmfs score are comparable to that of the sample in this study.

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