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Caries Patterns in the Primary Dentition: Cluster Analysis of a Sample of 5,169 Arizona Children 5-59 Months of Age

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Abstract

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Aim Cluster analysis was conducted on data from 5,169 United States (U.S.) Arizona children, age's 5-59-months with the goal of delineating patterns of caries in the primary dentition of pre-school children without *a priori* pattern definitions.

Methodology Cluster analyses were conducted using all data for children ages 0-4 years in aggregate: 1) for all subjects, and 2) for subjects without crowned restored teeth. Each of these two sets of analyses consisted of 8

differently specified cluster analyses as a validation procedure.

Results The caries patterns identified from the clustering analysis are: 1) smooth surfaces (other than the maxillary incisor), 2) maxillary incisor, 3) occlusal surfaces of first molars, and 4) pit and fissure surfaces of second molars.

Conclusion The cluster analysis findings were consistent with results produced by multidimensional scaling. These cross-validated patterns may represent resulting disease conditions from different risks or the timing of various risk factor exposures. As such, the patterns may be useful case definitions for caries risk factor investigations in children under 60 months of age.

Keywords dental caries, cluster analysis, multidimensional scaling, early childhood caries (ECC), caries patterns

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Introduction

Patterns of primary dentition dental caries encompassing differing teeth or tooth surfaces have been previously proposed (Johnsen *et al.*, 1984; Johnsen *et al.*, 1987; Greenwell *et al.*, 1990; Johnsen *et al.*, 1993; O'Sullivan and Tinanoff, 1993; Douglass *et al.*, 1994; Veerkamp and Weerheijm, 1995; O'Sullivan and Tinanoff, 1996; Psoter *et al.*, 2003;). This limited body of literature regarding the use of caries patterns as case definitions presents inconsistencies in the various proposed caries patterns,

as well as the use of *a priori*-defined patterns (Psoter *et al.*, 2004). This suggests that accurate early childhood caries (ECC) case definitions are yet to be validated.

Multidimensional scaling (MDS) analyses were previously conducted on data from 5,169 United States (U.S.) Arizona children ages 5-59-months with the goal of delineating patterns of caries in the primary dentition of pre-school children without *a priori* pattern definitions (Psoter *et al.*, 2003). This approach to caries pattern identification suggested caries patterns of: 1) smooth surface, other

than maxillary incisors, 2) maxillary incisors, 3) first molar occlusal surfaces, and 4) second molar pit and fissure surfaces; which are broadly consistent with the historical reports of ECC tooth surface patterns (Psoter *et al.*, 2004).

Cluster analysis findings may be applied in the interpretation of the MDS results, a preferred approach in the use of these complementary techniques (Arabie *et al.*, 1987). As with MDS, cluster analysis uses dissimilarity/similarity proximity measures to define variable relationships, however, different analytic algorithms are used. By limiting the cluster members to computed MDS spatial quadrants, accuracy may be enhanced in interpretation of the cluster analysis results. By testing for clustering within the MDS spatial orientations, the statistical validity of the relationships described by the spatial arrangements can be examined, an important step in the process of demonstrating the true existence of ECC caries patterns.

The specific aim of this study was to analytically test for clustering among tooth surfaces. In this way, analytic support for the MDS identified caries patterns may be established.

Methods

This study received human subjects' Institutional Review Board approval from the University of Connecticut Health Sciences Center, Yale University and New York University.

The original sampled cohort of Arizona children and the methods of examination have been described elsewhere (Tang *et al.*, 1997; Douglass *et al.*, 2001; Psoter *et al.*, 2003). Briefly, five calibrated examiners visually examined 5,171 Arizona pre-school children age 5-59 months old between February 1994 and September 1995. The children were recruited from Head Start programs, WIC programs, health fairs and private day care centers from a sample of the State's communities. Each of the study's communities had a minimum sample size of 25 children for each age-year 1-4. This study used data from 5,169 of the sampled children. Dental caries was diagnosed by visual examination only. Caries criteria were defined as a visual break in enamel surface, pit and fissure

discoloration with adjacent opacity, evidence of marginal ridge undermining, and anterior shadowing on transillumination. For this study, all tooth surfaces were classified as either caries or sound, with teeth originally having been scored as decayed, missing due to caries, or filled.

Contra-lateral paired surfaces were combined as single surface variables both as an intuitively logical procedure and following preliminary cluster analyses. These preliminary analyses demonstrated a first level and close clustering for each contra-lateral pair of primary dentition tooth surfaces; the subsequent analyses assessed these combined tooth surface variables for clustering (Norusis, 1993).

Cluster analyses were conducted using all data for children ages 0-4 years, in aggregate: 1) for all subjects, and 2) for subjects without crowned restored teeth. For each of these two sets of analyses (*i.e.* ages in aggregate, and ages in aggregate excluding subjects with crown restorations), analyses consisted of eight differently specified cluster analyses as a validation procedure.

These eight different cluster analyses involve two clustering methods using four proximity (similarity/dissimilarity) measures. The two hierarchical clustering methods employed were: 1) furthest neighbor (complete linkage, distance of two furthest points), and 2) average between group linkage (average distance of all pairs of cases between clusters). For each of these two methods the similarity/dissimilarity measures used were: 1) simple matching, 2) Hamann, 3) Euclidean squared distance, and 4) variance.

The furthest neighbor method requires cluster inclusion by a similarity to all cluster members and this technique produces compact highly related clusters (Aldenderfer and Blashfield, 1984). This method has been shown to provide a clear tree of relationships (Aldenderfer and Blashfield, 1984). The average between group linkage method uses an average of similarities of the variables under consideration with other cluster members and has been generally applied to the biologic sciences for classification scheme generation (Aldenderfer and Blashfield, 1984).

The simple matching similarity measure uses the summed cases' concordance cell data as a percentage of all cells of a 2x2 caries concordance/discordance table for each variable pairing. This

Table 1 Socio-demographics of study sample of 5,169 Arizona children 5-59 months of age

Age (months)	No.	Mean (SD)	
	5,169	36.5 (15.7)	
Age (years)	No.		%
	0	383	7.41
	1	995	19.25
	2	977	18.90
	3	1,276	24.69
	4	1,538	29.75
	Total	5,169	100.00
Gender	Female	2,469	47.77
	Male	2,697	52.18
	Total	5,169	100.00
Ethnicity	Nat. Amer.*	230	4.45
	Black	334	6.46
	Hispanic	2,490	48.17
	White	1,787	34.57
	Other	163	3.15
	Total	5,004	96.81
	Missing data	165	3.19
	Total	5,169	100.00
Education (highest grade of caregiver)	No (HS) [†]	532	10.29
	Some (HS)	762	14.74
	Completed (HS)	1,596	30.35
	Some college	1,609	31.13
	Total	4,472	86.52
	Missing Data	697	13.48
	Total	5,169	100.00
Income (self-reported household income)	<\$10,000	2,052	39.70
	\$10,000–20,000	1,028	19.89
	\$20,000–30,000	452	8.74
	≥\$30,000	534	10.33
	Total	4,066	78.66
	Missing Data	1,103	21.34
	Total	5,169	100.00

* Nat. Amer.: Native American. [†] (HS): High school.

produces a proximity value for the variable by variable proximity matrix. The Hamann similarity measure is similar to simple matching but adjusts the degree of concordance by discordance. The two dissimilarity measures, Euclidean squared distance and variance, were chosen as the same measures used in the multidimensional scaling model pre-

viously reported, providing a direct relationship for comparison. These latter two measures consider discordance in the numerator when computing a proximity value.

The process applied in the interpretation of the cluster analyses was to determine those clusters of tooth surfaces at the upper 40% distance level from baseline in dendrograms produced by each analysis. Dendrograms are pictorial tree-like representations of the similarity relationships of the factors under consideration (Figure 1). Distances in the dendrograms branches represent the tooth surfaces' similarity (or dissimilarity) in terms of the surfaces caries experience (Norusis, 1993). The 40% level was arbitrarily chosen as defining relatively distantly related clusters of tooth surfaces that may represent distinct caries patterns. A potential pattern was considered if a predominant number of the eight analyses demonstrated that particular clustering. This process established the potential caries patterns.

Results

Table 1 presents the socio-demographic descriptive statistics of the sample, which are also described elsewhere (Psoter *et al.*, 2003).

All age groups were considered in aggregate, first using all subjects and subsequently, restricting the analysis to those subjects without crown restorations (Table 2). The initial analysis identified the clusters (patterns) of:

- 1) smooth surfaces (other than the maxillary incisors),
- 2) maxillary incisor,
- 3) mandibular first molar occlusal surfaces,
- 4) maxillary first molar occlusal surfaces,
- 5) pit and fissure surfaces of maxillary second molars (inclusive of occlusal and upper lingual surfaces, in analyses of subjects without crowns, only),
- 6) pit and fissure surfaces of mandibular second molars (inclusive of occlusal and lower facial surfaces, in analyses of subjects without crowns, only).

These aggregated analyses differed from the previously reported age aggregated MDS analysis in that clustering continued to isolate each of the

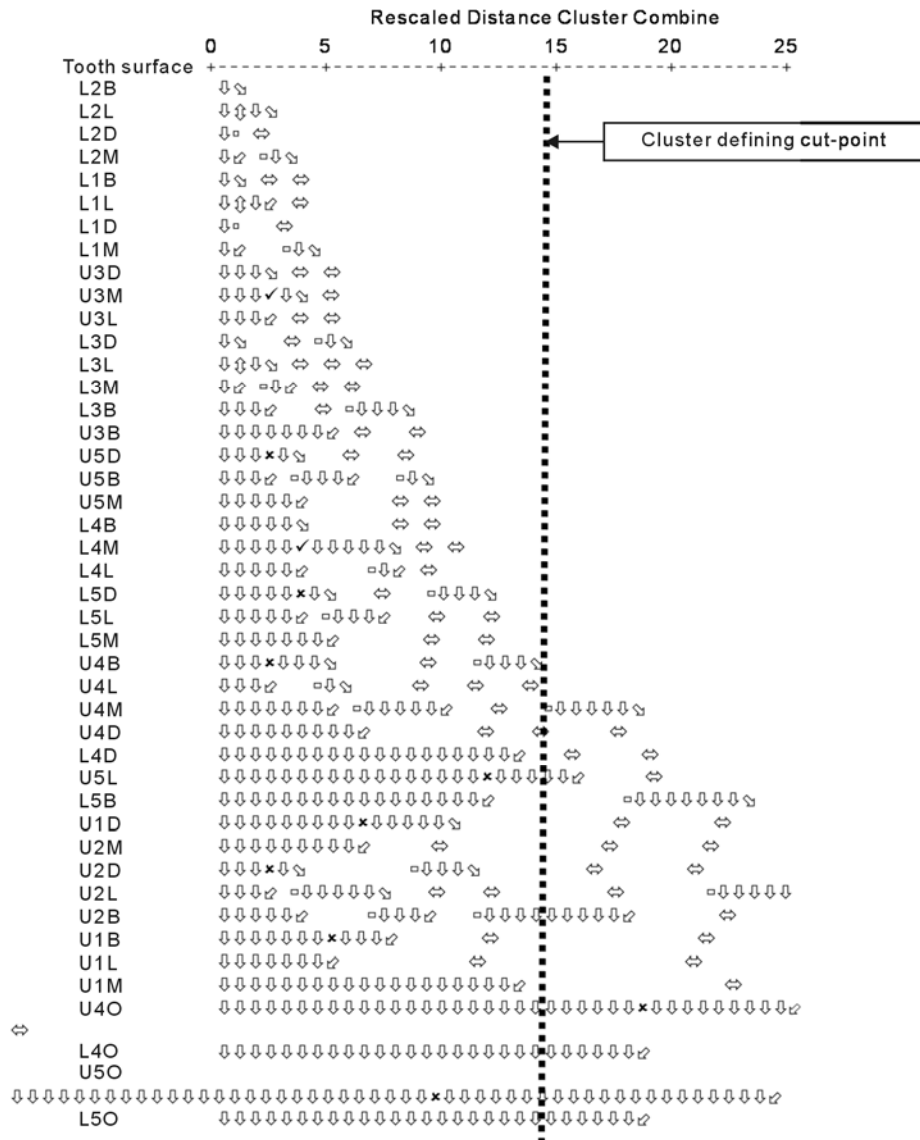


Figure 1 Sample Dendrogram using Complete Linkage from tooth surface cluster analysis

Contra-lateral paired surfaces are combined as single surface variables and are identified on the right column of the dendrogram, e.g., L2B is the lower tooth number 2's (mandibular lateral incisor) buccal (facial) surface. The similarities of each tooth surface to all other tooth surfaces in terms of caries or sound status is represented by the connecting lines, which length is a distance computed by the cluster algorithm. The distance is then standardized as the "rescaled distance," 0-25. Surface similarities are observed by the vertical distance between surfaces and the minimum horizontal distance along the rescaled distance. For example, L2: B, L, M and D are essentially identical in their caries/sound status; the four surfaces are vertically together and cluster at a close horizontal (rescaled) distance of approximately one (1). Likewise, the four L1 surfaces cluster together, and then at the next level, closely cluster with the L2 surfaces as observed by the vertical connecting line between the 2 groups of four surfaces at a distance of approximately 2.5. This is interpreted as the lower #1 and #2's (lower incisors) clustering together and being very similar in their caries status.

The study set an *a priori* distance to accept distinct independent clusters, i.e., groups of tooth surfaces that are distinctly different in their similarities of caries/sound status. The study distance threshold is the upper 40% of the dendrogram (> 15 rescaled distance) to define separate tooth surface groups as caries patterns, i.e., the horizontal distance is ≥ 15 before the next vertical connection with another cluster of surfaces.

The result is four clusters (groupings) of surfaces that connect higher than the 15 distance. They are the U and L 5's (maxillary and mandibular second primary molars) occlusal surfaces, U and L 4's (maxillary and mandibular first primary molars) occlusal surfaces, the upper teeth #1 and #2 surfaces (central and lateral primary incisors), and all other surfaces (by definition, smooth surfaces). Thus, the four caries patterns, 2nd molars, 1st molars, maxillary anteriors (incisors) and all other smooth surfaces.

Table 2 Cluster and MDS analyses results for caries of a sample of 5,169 Arizona children 5-59 months of age

Tooth surfaces	Cluster analyses			DMS analyses
	Age /years			Age /years
	0-4 [*]	0-4 [†]	0-4 [‡]	0-4 [§]
Smooth	×	×	×	×
Maxillary incisor proximal	×			
Maxillary incisor facial/lingual	×			
Any maxillary incisor surface		×	×	×
Maxillary first molar occlusal	×			
Maxillary second molar pit & fissure	×			
Mandibular first molar occlusal	×			
Mandibular second molar pit & fissure	×			
First molar occlusal		×	×	×
Second molar pit & fissure		× [¶]	×	×

*Analyses of subjects with and without crown restorations, hard clustering rule applied.

† All subjects, modified analysis (relaxation of cluster distance rule).

‡ Subjects without crown restorations (relaxation of cluster distance rule).

§ Analyses of subjects with and without crown restorations, four year olds.

¶ Occlusal surfaces, only.

four molar tooth under the strict dendrogram distance criteria. Notably, the maxillary first molar occlusal surface clustered somewhat closer with the smooth and maxillary incisor smooth surfaces. This was also observed in the MDS analysis of children < 36 months of age. A very minor relaxation (no more than 10%) of the initial clustering cut-point criterion produced four patterns, results that are identical to those from multidimensional scaling (Table 2), that is, clustering of the maxillary and mandibular first, and separately, second molars. The dendrograms for each of the eight analytic specifications were virtually identical in all cases. This result was also observed when subjects with crowned teeth were dropped from the analysis.

Discussion

Patterns of dental caries in the primary dentition of pre-school children have been described in the literature. The challenge of determining caries patterns is to analytically classify patterns that are likely not due to chance alone. Three common analytic techniques used to identify underlying relationships in data *e.g.* groupings or taxonomies, are factor analysis, multidimensional scaling and cluster analysis.

This paper reports patterns of primary dentition caries for a sample of U.S. Arizona pre-school children. Cluster analyses with no *a priori* pattern definitions were used to establish caries patterns. This report of the caries clustering of teeth supports the concept of patterns of caries in the early childhood in general, and specifically those patterns previously identified by multidimensional scaling analysis.

This complementary analytic approach of using multidimensional scaling and cluster analysis provides important, mutually confirmatory and validating findings. MDS is a useful first method utilized for representing any relationships of tooth surfaces with caries. A conceptual or perceptual, spatial orientation is produced from proximity dissimilarity/similarity) measures. Cluster analysis, which likewise utilizes dissimilarity/similarity measures, is recommended for use as a complement to MDS to assess the clustering within the spatial patterns produced (Arabie *et al.*, 1987). Though there is an intuitive reliability safeguard in these complementary analyses, in that similar spatial arrangements and clusters tend to be mutually supporting, the spatial vectoring of MDS only presents the orientation of the underlying homogeneity/heterogeneity groupings within the data. Clusters, *i.e.* non-random relationships, require the

application of a statistical analytic “clustering technique”. More specifically, it can be used to assess the quadrant assignment of the data partitioning produced by MDS, as well as to partition the quadrants further. Alternatively, MDS may be considered as the “rule” for cluster consideration, *e.g.* cluster assignments may not overlap MDS spatial quadrants boundaries.

Spatially, the upper and lower first, and separately, the second molars, were each identically vectored respectively in MDS. This finding supports the decision based on the MDS “rule” of cluster assignments being within MDS quadrants, to combine upper and lower teeth within the molar patterns, resulting in four caries patterns: 1) smooth surface, other than maxillary incisors, 2) maxillary incisors, 3) first molar occlusal surfaces, and 4) second molar pit and fissure surfaces. However, the cluster analysis results suggest some caution in aggregating the maxillary and mandibular first molar occlusal surfaces, and this pattern should be explored using independently generated data.

As previously described, the large sample size and age-specific cell sizes, as well as, the general diversity of the sample are study strengths (Psoter *et al.*, 2003). In terms of this analysis an additional strength was that multiple cross-validating analyses, two clustering methods (average and complete linkage), and multiple proximity measurements for clustering (squared Euclidean, variance, simple matching and Hamann) were utilized. Most importantly, *a priori* pattern definitions were not applied in this analysis.

A potential limitation was that interpretation of the dendrograms was conducted unblinded as to the MDS results. While the strict cluster cut off points precluded bias from this source in the initial cluster analyses interpretations, MDS results provided some guidance in the relaxation of the arbitrary cut off rule, an accepted approach in classification studies. The aggregations of maxillary and mandibular surfaces in the two molar patterns have an intuitive appeal, though cluster analysis suggests that maxillary first molar caries may be closely associated with smooth surface caries than with mandibular occlusal caries. The MDS analysis suggest that this may be a teeth surfaces association in the under 3-year olds. The molar aggregation presented here is further supported by Mantel-

Haenszel tests for associations, stratified by age-year. The common odds ratios (confidence intervals) for the association between caries on the maxillary and the mandibular molars (interactions not being statistically significant) was 3.98 (3.12, 5.07) for first molars, and 3.56 (2.77, 4.59) for the second molars.

An inherent bias in these results is that crowned teeth would associate surfaces without caries with those with caries among those teeth restored by crowns. Ten percent of the subjects with a history of caries (153/1,475) had one or more crowned teeth. Most of these cases were observed in 4-year olds suggesting that any resulting bias may be limited to that age group. To assess this potential bias, cluster analysis was conducted on 4-year olds with and without crowns. These analyses gave similar results with the additional relationships of the second molar occlusal surfaces with their maxillary lingual and mandibular facial surfaces being clearly identified as molar pattern component surfaces when subjects without crowns were removed from the analysis.

Dental caries patterns may reflect the result of the timing of a risk factor exposure and/or its temporal relation to other caries risk factors of different etiologic agents, host status or responses, or environmental conditions (Psoter *et al.*, 2004). Case definitions based on caries patterns may enhance the ability to identify ECC/risk factor associations and minimize misclassification (Psoter *et al.*, 2003). This approach has been successfully applied to examine race, ethnicity and socio-economic ECC health disparities (Psoter *et al.*, 2006). Dental caries patterns as disease case definitions may be utilized with analyses of ECC both independently and as validity co-analyses with other ECC case definitions in order to fully explore apparent observed risk/protective factors associations.

Conclusions

This paper reports patterns of primary dentition caries for a sample of Arizona pre-school children. The cluster analysis findings were consistent with results produced by multidimensional scaling. The proposed caries patterns may represent resulting

disease conditions produced by differing risks or the timing of various risk factor exposures. As such, the patterns may represent appropriate surface specific case definitions in caries risk factor studies in children under 60 months of age. The use of these patterns as case definitions should 1) help reduce non-differential disease misclassification and thereby 2) enhance the ability of an analysis to identify meaningful associations between suspected risk factors and ECC.

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