The effects of various dental procedures and patient behaviors upon nitrous oxide scavenger effectiveness

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Abstract

This prospective study of 36 children, ages 44–93 months, receiving nitrous oxide-oxygen under standardized conditions during routine dental procedures was conducted to determine what influence eight selected dental procedures and three patient behaviors had on ambient nitrous oxide (N_2O) levels in the dentist's breathing zone. Half the children received nitrous oxide-oxygen via a scavenging nasal mask. An infrared spectrophotometer analyzed the ambient N_2O level continuously throughout the procedure and the time-weighted average (TWA) for consecutive 15-sec intervals was recorded by a microprocessor. A video camera was used to synchronize the coded dental procedures and patient behaviors to the TWA ambient N_2O levels recorded. The results demonstrated that scavenging significantly reduced the dentist's exposure to ambient N_2O ($P < 0.05$, nonscavenged mean = 284.7 ppm; scavenged mean = 36.6 ppm), but the mean TWA N_2O concentration remained significantly higher, $P < 0.05$, than the 25-ppm level recommended by the National Institute for Occupational Safety and Health (NIOSH). Supplemental oral evacuation was the only dental procedure capable of reducing ambient N_2O to below NIOSH's recommendation when scavenging was employed. The administration of local anesthesia consistently created a significant increase in ambient N_2O levels. Patient behaviors of talking, crying, and movement also resulted in significant increases from baseline ambient N_2O levels. (Pediatr Dent 14:19–25, 1992)

Introduction

Chronic exposure to nitrous oxide (N_2O) has been linked to various health and safety concerns for dental personnel. Such exposure to N_2O has been associated with an increased prevalence of kidney and liver disease,[1] neurological disorders,[2, 3] infertility and reproductive difficulties,[1, 4-7] and bone marrow suppression.[8] Evidence also exists that impaired psychomotor performance can occur during exposure to trace amounts of N_2O.[9-10]

Earlier reports of such adverse health effects prompted the National Institute for Occupational Safety and Health (NIOSH) to sponsor two investigations to determine what minimum N_2O level: would interfere with optimum performance of perceptual, cognitive, and motor skills[11], and could be achieved in the dental operatory with a scavenging device.[12] Based upon the results of these investigations, NIOSH developed upper limit guidelines for N_2O exposure which stated that: "Occupational exposure to nitrous oxide, when used as the sole anesthetic agent, shall be controlled so that no worker is exposed at time weighted average concentrations greater than 25 ppm during anesthetic administration."[13] Although the American Dental Association recommended that scavenging devices be employed for reducing ambient N_2O levels to the lowest level possible,[14] numerous clinical studies involving scavengers have demonstrated the difficulty of reducing ambient N_2O to the level recommended by NIOSH.[15-19]

Variables in dental procedures (rubber dam utilization and supplemental evacuation) and in patient behaviors (movement, talking or crying) have been suggested to influence ambient N_2O concentrations in the dentist's breathing zone. However, earlier investigations of these variables have produced conflicting and inconclusive results.[12, 20-22] The purpose of this investigation was to determine what influence the performance of eight selected dental procedures and the occurrence of three patient behaviors had on ambient N_2O levels in the dentist's breathing zone. A better understanding of the dental procedures and patient behaviors which influence the production of peak ambient N_2O concentrations may identify when additional control measures beyond scavenging should be applied to improve compliance with the current NIOSH recommendation.

Materials and Methods

Subjects

All participants in this investigation were patients at the University of Florida College of Dentistry Faculty Practice Clinic. Indication for N_2O utilization was based on standard selection criteria and according to previously established guidelines.[23] Parental informed consent and University Institutional Review Board approval were obtained prior to subject participation in this investigation.

Thirty-six healthy children, who ranged in age from 44 to 93 months with a mean age of 64 months, participated in this study. Children were allocated randomly to two treatment groups, 18 per group. Group 1 subjects received N_2O via a scavenging nasal mask assembly, while Group 2 subjects received nonscavenged N_2O. Analysis of patient assignment found no statistical difference between the groups with regard to age and gender distribution. All subjects received routine restorative dental treatment. Procedures were performed with the aid of an assistant, use of local anesthesia, rubber dam and high speed evacuation. The duration of N_2O administration ranged from 17 to 40 min with a mean length of 24 min.

All subjects were assigned randomly to either an open operatory or a closed operatory. Operatory ventilation information was obtained in a manner previously reported.[24] The open operatory measured 4180 cubic ft and had a room air exchange rate of 5.3 room air changes per hour. The closed operatory measured 720 cubic ft and had a room air exchange rate of 8.4 room air changes per hour. Previous investigation determined that with the increased ventilation found in the closed operatory any influence that operatory size and ventilation may have had were offset, resulting in a nonsignificant environmental effect on ambient N_2O levels.[24]

N_2O Exposure

All subjects received N_2O with oxygen throughout the procedure from a portable N_2O machine (MXR®, Porter Instrument Co., Hatfield, PA). This unit and all rubber goods were obtained new and exclusively used for subjects participating in this investigation. No leaks were found in the unit's low and high pressure components when evaluated in the manner of Whitcher and coworkers.[25] All children received N_2O via the rapid induction method.[23] Each child initially was induced with 50% N_2O; this concentration was maintained during local anesthetic administration. It was reduced to a 40% concentration before application of the rubber dam. After initial tooth preparation was begun, the N_2O concentration was reduced further to 30% for the remainder of the dental procedure. N_2O in oxygen was administered at a standard flow rate of 4–5 L/min and was adjusted for each patient depending upon the degree of distention of the reservoir bag. Oxygen (100%) was administered for 5 min at the completion of the dental treatment.

Group 1 subjects received N_2O from a unit equipped with a small-sized scavenging mask assembly (Porter/Brown, Porter Instrument Co., Hatfield, PA) connected to the local evacuation system which was vented outside the building. The proper evacuation rate for scavenging was established by adjusting the rotameter, according to the manufacturer's recommendations, to produce an evacuation rate between 25 to 39 L/min (Porter Instrument Co., Hatfield, PA). Group 2 subjects received N_2O from the same N_2O unit and mask but without scavenging for removal of waste N_2O.

Gas Sampling Procedure

An infrared spectrophotometer (Miran 1B®, Foxboro, South Norwalk, CT) was utilized for monitoring waste N_2O levels. The spectrophotometer was set for infrared absorbance of N_2O at a wavelength of 4.68 μ and a path length of 0.75 meter. N_2O detection was established within a range of 0–2000 ppm. The unit was precalibrated by the manufacturer with baseline zeroing of the instrument performed before each use.

Ambient N_2O was monitored 20-22 in. from the subjects' noses at a location directly above their chests. This distance has been used previously[17, 19, 26] and was chosen to minimize interference from exhaled carbon dioxide and water vapor on spectrophotometer accuracy. Surgical masks worn by the dentist and assistant also served to further reduce these effects. Ambient N_2O concentrations registered by the spectrophotometer were recorded with a microprocessor (DL332F Datalogger®, Foxboro, South Norwalk, CT). Data were recorded beginning with the introduction of N_2O and terminated after the end of each appointment. The microprocessor collected readings from the spectrophotometer at 1-sec increments and saved data at 15-sec intervals continuously throughout each appointment. Ambient N_2O data were transferred to a microcomputer for storage, coding and statistical analysis.

Videotaping Procedure

A video cassette recorder (Video Camcorder CPR #250®, RCA Corp., Indianapolis, IN) was utilized to record each dental appointment. Time was synchronized to the microprocessor with the use of a clock placed in the camera field. Videotapes were reviewed to identify each occurrence and duration of eight dental procedures and three patient behaviors. Procedural variables included: topical anesthetic application, local anesthetic administration, water rinsing with oral evacuation, mouth prop placement, rubber dam application, high speed tooth preparation with oral evacuation, hand instrumentation, and restoration placement. Behavioral variables included: patient talking, crying, and movement. The specified procedures and behaviors were coded to the associated mean ambient N_2O levels (the 15-sec interval TWA values) which previously were entered into a digital database for storage.

Statistical Analysis of Data

The mean concentration of ambient N_2O associated with each variable as well as group baseline N_2O levels were determined. Intergroup analysis was accomplished by comparing the population means (all 15-sec interval TWA values) between the two groups by use of Analysis of Variance (ANOVA). Intragroup information was analyzed by comparison of each procedural and behavioral mean ambient N_2O level to the respective group baseline ambient N_2O level (ANOVA). Significance was established at $P < 0.05$ with Fisher PLSD test and Scheffe's F-test.

Table 1. Comparison of ambient N_2O levels for scavenged and nonscavenged groups

Group	N*	*Ambient Nitrous Oxide Levels (PPM)*	
		Mean ± SEM	*Range*
Scavenged	1732	36.6 ± 1.1†	0–401.6
Nonscavenged	1594	284.7 ± 2.7†	0–601.8

* N represents the number of 15 sec-intervals observed for each group.

† Represents significant differences between group means at $P < 0.05$, using ANOVA with Fisher PLSD and Scheffe F-test.

Results

Comparison of the scavenged and nonscavenged groups demonstrated the scavenging system's efficiency at reducing ambient N_2O levels (Table 1). Statistical analysis showed that although scavenging significantly reduced ambient N_2O levels from a mean of 284.7 ppm (nonscavenged) to a mean of 36.6 ppm (scavenged), mean TWA concentrations were still significantly higher than the current NIOSH recommendation ($P < 0.05$).

Determination of Baseline Ambient N_2O Levels

The three different N_2O concentrations administered to each patient during the treatment appointment resulted in differing mean ambient N_2O levels.[24] For statistical analysis the ambient N_2O readings occurring during the selected variables were compared to the mean baseline ambient N_2O levels found when no selected dental procedure or patient behavior was observed for each of the three N_2O concentrations delivered. The baseline ambient N_2O levels (mean ± SEM) for Group 1 (scavenged) subjects were determined from 670 fifteen-sec intervals and calculated to be 35.2 ± 2.3 ppm during 50% N_2O administration, 36.2 ± 3.0 ppm during 40% N_2O, and 28.8 ± 1.7 ppm during 30% N_2O. The baseline ambient N_2O levels (mean ± SEM) for Group 2 (nonscavenged) subjects were determined from 679 fifteen-sec intervals and calculated to be 230.4 ± 10.0 ppm during 50% N_2O administration, 294.8 ± 7.1 ppm during 40% N_2O, and 291.3 ± 4.8 ppm during 30% N_2O.

Procedural Influences on Ambient N_2O Levels

Table 2 shows mean ambient N_2O levels, mean change from baseline, and the frequency of 15-sec intervals for each procedural variable observed with Group 1 (scavenged) and Group 2 (nonscavenged) subjects. For subjects in both groups, significant decreases from baseline ambient N_2O levels occurred during oral evacuation associated with either water rinsing or high speed tooth preparation. Significant increases from

Table 2. Procedural ambient N_2O levels (mean PPM ± SEM) compared to baseline

Procedure	*Group I*		*Group II*	
	Scavenged Mean N_2O Levels (PPM)	*Scavenged Change From Baseline*	*Nonscavenged Mean N_2O Levels (PPM)*	*Nonscavenged Change From Baseline*
Topical anesthetic administration	30.4 ±3.7 N = 77	–4.8 ±3.7	304.8 ±13.4 N = 56	74.4 ±13.4†
Local anesthetic administration	72.2 6.7 N = 111	37.0 6.7†	351.9 10.7 N = 123	121.5 10.7†
Water rinse with evacuation	19.2 1.3‡ N = 170	–12.5 1.3†	229.2 11.0‡ N = 87	–51.7 11.8†
Mouth prop placement	61.5 7.9 N = 28	25.3 7.8•	338.5 24.0 N = 22	43.7 27.3
Rubber dam application	44.7 5.8 N = 51	8.5 5.8	336.6 14.4 N = 41	41.8 14.4•
High-speed preparation with evacuation	22.9 1.5‡ N = 275	–9.7 1.5•	219.8 6.6‡ N = 181	–73.5 6.6†
Hand instrumentation	37.2 6.6 N = 29	8.4 6.8	301.8 12.5 N = 39	10.5 12.4
Restoration placement	32.1 ± 3.6 N = 145	3.3 ± 3.6	283.7 ± 8.5 N = 116	–7.6 ± 8.5

Significant differences from respective baseline N_2O levels, using ANOVA, are shown at $P < 0.05$ with • representing significance with Fisher PLSD test and † representing significance with Fisher PLSD and Scheffe F-test. N is the frequency of 15 sec intervals observed for each procedure and ‡ represents dental procedures during which multiple concentrations of N_2O were delivered.

baseline ambient N_2O levels for scavenged subjects occurred only during local anesthetic administration and mouth prop placement (Fig 1, next page, illustrates procedural influences on Group 1 ambient N_2O levels) whereas the nonscavenged subjects demonstrated statistically significant increases from baseline levels during topical anesthetic administration, local anesthetic administration as well as during rubber dam placement.

Behavioral Influences on Ambient N_2O Levels

Table 3 shows mean ambient N_2O levels, mean change from baseline, and the frequency of 15 sec intervals for each behavioral variable observed with Group 1 (scavenged) and Group 2 (nonscavenged) subjects. Subjects in both groups demonstrated statistically significant increases in ambient N_2O levels during patient talking, crying and movement. Further analysis of ambient N_2O levels during patient crying revealed a direct correlation with the concentration of N_2O being administered to the patient. Group 1 patient crying yielded significantly higher ambient N_2O levels (140.3 ± 17.2 ppm) during 50% N_2O administration compared to crying at 40% N_2O administration (65.5 ± 17.1 ppm) or at 30% N_2O administration (32.9 ± 3.1 ppm). Fig 2, next page, illustrates behavioral influences on Group 1 ambient N_2O levels. The same observation was made with the nonscavenged subjects. Group 2 patient crying during 50% N_2O administration produced significantly higher ambient N_2O levels (399.2 ± 22.6) than crying at 40% N_2O administration (315.7 ± 19.2) or at 30% N_2O administration (306.0 ± 7.4). For both groups, ambient N_2O levels associated with crying during 30% N_2O administration were not significantly different from their respective baseline levels.

Combined Procedural and Behavioral Influences on Ambient N_2O Levels

Analysis of patient behavior during local anesthetic administration demonstrated a behavioral influence on ambient N_2O levels. Significantly lower ambient N_2O levels ($P < 0.001$) were associated with subjects judged to be cooperative during local anesthetic administration (56.1 ppm ± 6.1) when compared to uncooperative, talking and/or crying subjects receiving local anesthesia (164.0 ppm ± 14.4).

Discussion

When comparing these findings to other published reports, it is important to consider several factors. First, recent technological advances have made gas detection and data collection more practical and accurate. Contemporary studies utilizing this advanced technology reflect clinical exposure levels more accurately and reliably. Second, since ambient N_2O levels decrease with increasing distance from the source,[25, 27-29] sampling probe placement is an important factor to evaluate when comparing nonstandardized reports. The results obtained at the 22-in. probe distance reported in this study probably underestimated the ambient N_2O levels located nearer the patient's nose. Third, the concentration of N_2O delivered to the patient, which varies between 30–50% among studies, will influence the reported results because as the concentration of N_2O administered increases, so do ambient N_2O levels in the dentists' breathing zone.[24, 30] Fourth, the scavenging system tested in various studies has not been standardized. The Brown scavenging system was selected intentionally for this investigation because of its proven superiority to other mask designs.[15, 18, 22, 26, 31] The outer mask is open at the periphery and permits effective evacuation of escaping gas around a loosely fitted nosepiece. Fifth, since gas leakage from equipment with loose connections and tubing is commonplace,[16] results from studies using im-

Table 3. Behavioral ambient N_2O levels (mean PPM ± SEM) compared to baseline

	Group I		*Group II*	
Behavior	*Scavenged Mean N_2O Levels (PPM)*	*Scavenged Change From Baseline*	*Nonscavenged Mean N_2O Levels (PPM)*	*Nonscavenged Change From Baseline*
Talking	101.4 ± 7.9‡ N = 62	67.4 ± 7.9†	347.2 ± 13.6‡ N = 47	68.1 ± 13.5†
Crying at 50% N_2O	140.3 17.2 N = 20	105.1 16.8†	399.2 22.6 N = 21	168.8 22.1†
Crying at 40% N_2O	65.5 17.1 N = 13	29.3 16.4•	315.7 19.2 N = 29	20.9 18.8•
Crying at 30% N_2O	32.9 3.1 N = 23	4.1 6.8	306.0 7.4 N = 87	14.7 7.4
Patient movement	55.9 ± 6.9‡ N = 29	25.8 ± 10.4•	325.4 ± 14.7‡ N = 95	52.2 ± 13.8†

Significant differences from respective baseline N_2O levels, using ANOVA, are shown at $P < 0.05$ with • representing significance with Fisher PLSD test and † representing significance with Fisher PLSD and Scheffe F-test. N is the frequency of 15 sec intervals observed for each procedure and ‡ represents behaviors during which multiple concentrations of N_2O were delivered.

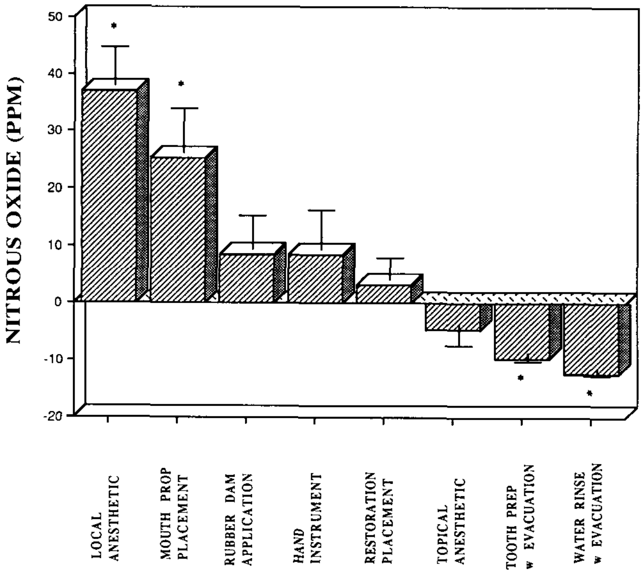

Fig 1. Dental procedural influences (horizontal axis) on ambient N_2O levels (vertical axis) expressed as the ppm (mean ± SEM) Time Weighted Average (TWA) change from the corresponding baseline N_2O concentrations for scavenged subjects. Significant changes from baseline are identified.

properly leak-tested equipment should be viewed with caution. The frequency of leakage is such that dentists are advised to maintain and test their nitrous oxide equipment regularly. Sixth, when considering the NIOSH recommended exposure limit for N_2O one should be aware that the 25 ppm TWA value is based on research conducted in the middle 1970s which attempted to determine trace anesthetic gas influence on perceptual, cognitive and motor skills.[9, 11] That research centered on psychomotor performance and was unrelated to adverse health effects from such an exposure. Attempts to verify this data have been unsuccessful[32-33] thereby challenging the original conclusions upon which the 25 ppm TWA recommendation was based. Seventh, the American Conference of Governmental Industrial Hygienists (ACGIH) has established a threshold limit value for N_2O exposure that differs from NIOSH's. The ACGIH recommendation is 50 ppm TWA N_2O for an 8-hr exposure.[34] The Occupational Safety and Health Administration (OSHA) has yet to adopt a permissible exposure limit but probably will utilize one of these recommendations. The adopted recommendation would become the enforcement level under OSHA's general duty clause which protects employees from hazards in the workplace. The current data suggest that, even in the presence of scavenging, current N_2O exposure guidelines may be unattainable in the dental office. Furthermore, recommendations based on biological influences of ambient N_2O have been proposed in Europe. Biochemical investigation of dentists and anesthetists chronically exposed to ambient N_2O levels in excess of 400 ppm have demonstrated altered vitamin B_{12} metabolism and impaired synthesis of DNA as measured with the deoxyuridine suppression test.[35, 36] Exposure limits of 400 ppm N_2O TWA per anesthetic administration[36] and a continuous exposure limit of 100 ppm N_2O TWA for an 8-hr period[31] have been suggested as safe and reasonably attainable in the dental setting.[37]

N_2O has been used widely in pediatric dentistry to manage the behavior of anxious children. Behaviors displayed in 3–5 year-old children requiring injections for dental treatment indicated that certain behavioral changes, such as increased talking and whimpering, were precedents to disruptive behavior.[38] In the present study, such behaviors were shown to influence ambient N_2O levels particularly during local anesthetic administration. Patient crying usually was quite vocal during this procedure and resulted in significant increases in ambient N_2O levels. Crying displayed during the remainder of the appointment, however, was generally less intensive (whimpering) and had little influence on ambient N_2O levels. The difference in mean ambient N_2O levels according to the type of crying displayed may reflect limits of the scavenging system's ability to maintain efficiency during changing intensity levels of patient crying or may be related to periods of breathholding by the child during crying.

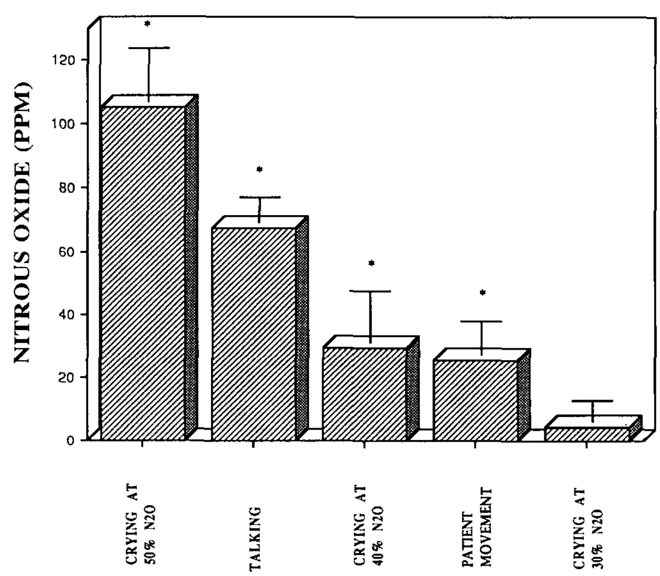

Fig 2. Patient behavioral influences (horizontal axis) on ambient N_2O levels (vertical axis) expressed as the ppm (mean ± SEM) Time Weighted Average (TWA) change from the corresponding baseline N_2O concentrations for scavenged subjects. Change from baseline N_2O levels by concentration of N_2O administered to the patient is shown for patient crying. Significant changes from baseline are identified.

In a broader sense, uncooperative child behavior generally has been thought to produce an increase in ambient N_2O levels in the breathing zone of the dentist.[21] However, limited data are available to support this assumption. The results here clearly demonstrated the influence patient behavior had on ambient N_2O levels during one specific procedure, local anesthetic administration. The present investigation supported earlier results demonstrating the patient's behavioral influence upon ambient N_2O levels[20, 21] but refuted another study examining the effect of controlled talking.[22]

Procedural influences on ambient N_2O levels were evaluated by Christensen and coworkers[22] during the scavenged administration of a 30% N_2O concentration to controlled subjects. They concluded that rubber dam isolation did not significantly affect levels of ambient nitrous oxide, even though the reported TWA ambient N_2O levels decreased from 192 to 109 ppm. Their results conflicted with an earlier study by Almquist and Young[39] which reported a 30% reduction in ambient N_2O levels during rubber dam isolation. The results of the present investigation failed to demonstrate any significant influence of rubber dam placement on ambient N_2O levels. This finding confirmed a more recent report which stated that rubber dam placement did not decrease ambient N_2O exposure to the dentist but simply redirected the flow of N_2O out the sides of the rubber dam, as demonstrated with infrared imaging.[40]

Carlsson and coworkers[20] also visualized waste N_2O by a thermocamera technique and compared the dispersion of N_2O during dental treatment under different conditions. The results showed that if the patient started to mouthbreathe, talk, or cough, the N_2O concentration increased in front of the dentist. Their demonstration that perioral placement of a high vacuum evacuation produced a significant reduction in the amount of N_2O was confirmed by the findings reported here. This report is the first investigation to demonstrate that supplemental oral evacuation, during scavenged N_2O administration, reduced ambient N_2O to levels below the current NIOSH recommendation.

Conclusions

1. Scavenging significantly reduced ambient N_2O levels in the dentist's breathing zone but not to the level recommended by NIOSH.
2. Supplemental oral evacuation, in conjunction with the scavenging device tested, produced a significant reduction in ambient N_2O levels to a concentration below the 25 ppm recommended by NIOSH.
3. Patient talking, crying and/or breath-holding during local anesthetic administration resulted in a three-fold increase in ambient N_2O levels compared to levels observed for cooperative children receiving local anesthesia.
4. Supplemental oral evacuation should be employed in conjunction with the scavenging system during N_2O administration to children, particularly during dental procedures or patient behaviors most likely to result in increased environmental N_2O exposure to the dentist and staff.

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Future Annual Session Sites

May 21–26, 1992	The Westin Hotel, Seattle, WA
May 27–June 1, 1993	Hyatt Regency Crown Center and Westin Crown Center, Kansas City, MO
May 26–31, 1994	The Walt Disneyworld Dolphin, Orlando, FL
May 25–30, 1995	Hyatt Regency San Francisco, San Francisco, CA
May 24–28, 1996	Chicago Marriott Hotel, Chicago, IL