IMPROVING MICROBIAL AIR QUALITY IN AIR-CONDITIONED MASS TRANSPORT BUSES BY OPENING THE BUS EXHAUST VENTILATION FANS

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Abstract. The air quality in air-conditioned mass transport buses may affect bus drivers' health. In-bus air quality improvement with the voluntary participation of bus drivers by opening the exhaust ventilation fans in the bus was implemented in the Seventh Bus Zone of Bangkok Mass Transit Authority. Four bus numbers, including bus numbers 16, 63, 67 and 166, were randomly selected to investigate microbial air quality and to observe the effect of opening the exhaust ventilation fans in the bus. With each bus number, 9 to 10 air-conditioned buses (total, 39 air-conditioned buses) were included. In-bus air samples were collected at 5 points in each studied bus using the Millipore Air Tester. A total of 195 air samples were cultured for bacterial and fungal counts. The results reveal that the exhaust ventilation fans of 17 air-conditioned buses (43.6%) were opened to ventilate in-bus air during the cycle of the bus route. The means ± SD of bacterial counts and fungal counts in the studied buses with opened exhaust ventilation fans (83.8 ± 70.7 and 38.0 ± 42.8 cfu/m^3) were significantly lower than those in the studied buses without opened exhaust ventilation fans (199.6 ± 138.8 and 294.1 ± 178.7 cfu/m^3), p<0.0005. All the air samples collected from the studied buses with opened exhaust ventilation fans were at acceptable levels (<500 cfu/m^3) compared with 4.6% of the air samples collected from the studied buses without opened exhaust ventilation fans, which had high levels (>500 cfu/m^3). Of the studied buses with opened exhaust ventilation fans (17 buses), the bacterial and fungal counts after opening the exhaust ventilation fans (68.3 ± 33.8 and 28.3 ± 19.3 cfu/m^3) were significantly lower than those before opening the exhaust ventilation fans (158.3 ± 116.9 and 85.3 ± 71.2 cfu/m^3), p<0.005.

INTRODUCTION

Indoor air quality is based on specific contaminants, especially house dust mites, cockroaches, pollen, and microbial agents. Many bioaerosol related illnesses, including allergic reactions and respiratory infections, are associated primarily with indoor environments, especially when ventilation is poor (Hansen, 1991; Nelson and Skufca, 1991). A previous study showed that human activities provided a major source of bioaerosols in indoor air and persons residing in air-conditioned homes seemed to have a higher frequency of respiratory complaints than those living in naturally ventilated homes (Kodama and McGee, 1996). In addition, poor ventilation can contribute to the spread of respiratory infections for which people are the source, such as measles, influenza, chickenpox, and tuberculosis (Burge, 1987; Riley and Nardell 1989; Mendell and Smith, 1990; WHO,1990; Zweers,1992). Anywhere that has poor indoor air quality has a potential affect on humans and society by either reducing quality of life or lost economic costs. In a city, humans spend most of the time travelling, especially in air-conditioned mass transport buses, where people crowd together in a limited area. The results from a previous study in mass transport buses in the Seventh Bangkok Mass Transit Bus Zone showed 16 of 180 air samples collected from the studied air-condi-

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tioned buses had high levels of bacterial and fungal counts (>500 cfu/m^3). Approximately 33% of the studied air-conditioned buses (12/36 buses) had at least 1 point of in-bus air sample with a high level of microbial counts (>500 cfu/m^3) (Luksamijarulkul *et al*, 2004). The detection of high levels of microbial count is an indicator of over-crowding and/or inadequate air ventilation in the studied buses. The ventilation strategy and the cleaning program of in-bus environments (seats, curtains and floor) and air conditioners in the buses were recommended. These recommended interventions were considered in the meeting of bus drivers of the Seventh Bangkok Mass Transit Bus Zone and they were accepted for implementation. The cleaning program on in-bus environments (seats, curtains and on the floor) and air conditioners of the buses was done in all the mass transport buses in the studied bus zone, whereas, the ventilation strategy by opening the exhaust ventilation fans in air-conditioned buses was implemented by voluntary participation of the bus drivers. This study attempts to demonstrate the effect of opening the exhaust ventilation fans on the microbial counts in the air-conditioned mass transport buses. If opening the exhaust ventilation fans can reduce the microbial counts in the studied air-conditioned buses, it will be extended to other bus zones of the Bangkok Mass Transit Authority. The air quality of air-conditioned buses and the working life quality of the bus drivers of the Bangkok Mass Transit Authority will be improved.

MATERIALS AND METHODS

Study design and study buses

Participatory action research (PAR) was applied to conduct the study. In-bus air quality was reported in a previous study (Luksamijarulkul *et al*, 2004). The recommended interventions, including a ventilation strategy and a cleaning program of the in-bus environments and air conditioners in the air-conditioned buses were revealed at a meeting of bus drivers of the Seventh Bangkok Mass Transit Bus Zone. The bus drivers discussed and accepted the recommended interventions. Opening of the exhaust ventilation fans in air-conditioned buses was implemented by voluntary participation of the bus drivers, because they had never used the exhaust ventilation fans in their buses.

The Seventh Bangkok Mass Transit Bus Zone consisted of 3 bus-stop zones, including U-Srinarong, U-Otoko-3 and U-Thait. For investigating the microbial air quality in air-conditioned buses, bus numbers 16 and 67 were randomly selected from the first bus-stop zone (U-Srinarong), and bus numbers 63 and 166 were randomly selected from the second and the third bus-stop zones (U- Otoko-3 and U-Thait, respectively). Nine to ten air-conditioned buses of each bus number (the ratio was about 1:2 to 1:3) were included in the study. A total of 39 air-conditioned buses were studied from March to May 2004. Under real life conditions of the bus route, the researcher observed the opening of the exhaust ventilation fans in each bus, and in-bus air samples were collected to assess the microbial air quality. After the observation, the studied air-conditioned buses were divided into 2 groups, the first group was the studied air-conditioned buses with the opened exhaust ventilation fans (17 buses) and the second group was those without the opened exhaust ventilation fans (22 buses). In addition, open-air buses of each bus number were randomly selected also, 2-4 open-air buses (total, 12 open-air buses) were included in the study to use as a comparison group.

Air sample collection and laboratory methods

In-bus air samples from 5 points in each studied bus were obtaind, before starting at the bus station, at a middle distance, at the terminal station, at the middle distance again and upon returning to the bus station again, were collected from 8.00 to12.00 AM. A total of 195 air samples from the studied air-conditioned buses (85 samples from the buses with opened exhaust ventilation fans and 110 samples from buses without opened exhaust ventilation fans) and 60 air samples from the studied open-air buses were collected to investigate the total bacterial and fungal counts. In addition, 9 outdoor air samples were collected from the bus station (3 samples), the middle distance (3 samples), and the terminal station (3 samples) for each bus number. Air samples were collected and measured using the Millipore Air Tester (M Air T). The microorganisms were impacted onto an agar surface in accordance with the USP reference method. The M Air T sieve has 967 holes to optimize colony distribution and reduce colony overlapping. The cassettes have a consistent filling level and flat surface, which helps ensure that the samples are from the same volume of air during each test. At a constant air sample flow of 140 liters/minutes, air was collected for 250 liters. Inoculated agar plates were incubated at 37ºC, 3 days for bacterial count and at 25ºC, 5 days for fungal counts. After incubation, the bacterial and fungal colonies were observed every day. Total colonies on the third day and the fifth day were counted and calculated by the formula as follows:

$$\text{Total count in the air sample (Colony forming unit or cfu/m}^3\text{)} = \frac{\text{Total colonies} \times 10^3}{250}$$

Interpretation of microbial counts in this study

The American Conference of Governmental Industrial Hygienist (ACGIH) Committee suggested that the presence of bacterial or fungal counts exceeding 500 cfu/m^3 in an office workplace was an indication of poor ventilation or over-crowding and in need of remedial action (Seitz, 1989). Therefore, the interpretation in the present study was as follows: if the bacterial count and/or fungal count were more than 500 cfu/m^3, it indicated poor ventilation or an unsanitary condition of in-bus air in the studied buses.

Data analysis

Descriptive statistics including percentage, mean ($\bar{X}$), and standard deviation (SD) were used for describing the microbial air quality in the studied buses. The *t*-test was used for analyzing the differences in the means of the microbial counts between the studied air-conditioned buses with and without opened exhaust ventilation fans. The critical level of $\alpha = 0.05$ was used for statistical significance.

RESULTS

General characteristics and the percentage of the studied air-conditioned buses with opening exhaust ventilation fans

The studied buses included 39 air-conditioned buses. The studied air-conditioned buses are orange and yellow in color, except bus number 166, which is blue. They have 2 doors, in the front and in the middle of the buses, and the windows are closed. Although, there are 2 exhaust ventilation fans in each bus, they are usually closed. In addition, 12 open-air buses used for the comparison group are red and white and have 2 doors in the middle. They have approximately 20 windows, but no ventilation fans. After the recommended interventions were implemented, there were 17 air-conditioned buses which had opened exhaust ventilation fans by observation during the cycle of the bus route (43.6%) and 22 air-conditioned buses without opened exhaust ventilation fans (56.4%). Bus number 16 had the highest percentage of opened exhaust ventilation fans (70%), and bus number 166 had the lowest percentage of opened exhaust ventilation fans (22.2%). All the studied buses run through crowed communities. The traffic is busy all day, especially during the rush hours, but not on Sunday and public holidays. Only bus number 166 uses the express way. Some general characteristics and the percentages of the studied buses with opened exhaust ventilation fans are shown in Table 1.

Microbial air quality: comparison between the studied buses with and without opened exhaust ventilation fans

A total of 195 air samples collected from the 39 air-conditioned buses (85 samples collected from 17 buses with opened exhaust ventilation fans and 110 samples collected from 22 buses without opened exhaust ventilation fans) were analyzed. The mean ± standard deviation (SD) of bacterial counts in the studied buses with opened exhaust ventilation fans was 83.8 ± 70.7 cfu/m^3, compared to 199.6 ± 138.8 cfu/m^3 in the studied buses without opened exhaust ventilation fans ($p<0.0005$). The mean ± SD of fungal counts in the studied buses with opened exhaust ventilation fans was 38.0 ± 42.8 cfu/m^3 compared to 294.1 ± 178.7 cfu/m^3 in that of the studied buses without opened exhaust ventilation fans ($p<0.0005$). In detail, the mean ± SD of bacterial counts or fungal counts in each studied bus line with opened exhaust ventilation fans was significantly lower than that of each studied

Table 1
Some characteristics and percentages of the studied air-conditioned buses with opened exhaust ventilation fans in the buses.

Bus no./Type of studied bus	Total No. of buses	Starting depot / Terminal depot color	No. studied	No. (%) of studied buses with opened exhaust ventilation fans
Bus number 16		U-Srinarong / Surawong		
Air-conditioned buses	25	Orange and yellow	10	7 (70.0)
Open-air buses	8	red and white	3	-
Bus number 63		U- Otoko III / Victory Monument		
Air-conditioned buses	19	Orange and yellow	10	4 (40.0)
Open-air buses	11	red and white	3	-
Bus number 67		Wat Samiannari / Central Rama III		
Air-conditioned buses	19	Orange and yellow	10	4 (40.0)
Open-air buses	9	red and white	4	-
Bus number 166		Muangthong / Victory Monument		
Air-conditioned buses	29	Blue	9	2 (22.2)
Open-air buses	5	red and white	2	-
Total		-		
Air-conditioned buses	92	-	39	17 (43.6)
Open-air buses	33	red and white	12	-

Table 2
Mean and standard deviation of microbial counts in in-bus air samples divided by each bus number.

Bus number / Type	No. of studied buses	No. of air samples	$\overline{X}$ ± SD of bacterial counts (cfu/m^3)	$\overline{X}$ ± SD of fungal counts (cfu/m^3)
No.16: Air-conditioned buses				
- with opened ventilation fans	7	35	64.3 ± 45.7[a]	19.7 ± 12.0[b]
- without opened ventilation fans	3	15	189.3 ± 150.3[a]	72.7 ± 52.8[b]
Open-air buses	3	15	279.3 ± 120.2	123.3 ± 63.2
No.63: Air-conditioned buses				
- with opened ventilation fans	4	20	112.0 ± 94.6[c]	64.5 ± 64.1[d]
- without opened ventilation fans	6	30	213.0 ± 143.2[c]	109.0 ± 81.0[d]
Open-air buses	3	15	394.0 ± 132.0	199.3 ± 112.2
No.67: Air-conditioned buses				
- with opened ventilation fans	4	20	76.0 ± 82.2[e]	37.5 ± 20.0[f]
- without opened ventilation fans	6	30	207.3 ± 99.6[e]	93.3 ± 66.4[f]
Open-air buses	4	20	430.5 ± 180.8	263.5 ± 138.2
No.166: Air-conditioned buses				
- with opened ventilation fans	2	10	111.0 ± 37.0[g]	38.0 ± 21.0[h]
- without opened ventilation fans	7	35	186.0 ± 161.5[g]	220.3 ± 293.5[h]
Open-air buses	2	10	242.0 ± 203.4	196.0 ± 94.4
Total : Air-conditioned buses				
- with opened ventilation fans	17	85	83.8 ± 70.7[i]	38.0 ± 42.8[j]
- without opened ventilation fans	22	110	199.6 ± 138.8[i]	294.1 ± 178.7[j]
Open-air buses	12	60	352.2 ± 174.2	201.2 ± 119.6
Out-door air	-	36	294.1 ± 178.7	248.3 ± 170.9

[a, c] Statistical significance , $p<0.005$; [b, e, f, i, j] Statistical significance $p<0.0005$; [d, g] Statistical significance, $p < 0.05$

Table 3
Number and percentage of air samples collected from the studied buses with high microbial counts (> 500 cfu/m^3).

Air samples collected from each bus number	No. of air samples	No (%) of air samples with high microbial counts (> 500 cfu/m^3)*		
		Bacteria	Fungi	Either bacteria or fungi
No. 16 : Air-conditioned buses				
- with opened ventilation fans	35	0 (0.0)	0 (0.0)	0 (0.0)
- without opened ventilation fans	15	1 (6.7)	0 (0.0)	1 (6.7)
Open-air buses	15	1 (6.7)	0 (0.0)	1 (6.7)
No. 63 : Air-conditioned buses				
- with opened ventilation fans	20	0 (0.0)	0 (0.0)	0 (0.0)
- without opened ventilation fans	30	1 (3.3)	0 (0.0)	1 (3.3)
Open-air buses	15	3 (20.0)	0 (0.0)	3 (20.0)
No. 67 : Air-conditioned buses				
- with opened ventilation fans	20	0 (0.0)	0 (0.0)	0 (0.0)
- without opened ventilation fans	30	0 (0.0)	0 (0.0)	0 (0.0)
Open-air buses	20	5 (25.0)	2 (10.0)	7 (35.0)
No. 166 : Air-conditioned buses				
- with opened ventilation fans	10	0 (0.0)	0 (0.0)	0 (0.0)
- without opened ventilation fans	35	1 (2.9)	2 (5.7)	3 (8.6)
Open-air buses	10	1 (10.0)	1 (10.0)	2 (20.0)
Total : Air-conditioned buses				
- with opened ventilation fans	85[a]	0 (0.0)	0 (0.0)	0 (0.0)
- without opened ventilation fans	110[b]	3 (2.7)	2 (1.8)	5 (4.6)
Open-air buses	60	10 (16.7)	3 (5.0)	13 (21.7)

* Total bacterial or fungal counts >500 cfu/m^3 indicate poor ventilation or unsanitary conditions (Seitz, 1989)
[a] 97.8% of air samples (83/85) had the microbial count less than 300 cfu/m^3
[b] 79.1% of air samples (87/110) had the microbial count less than 300 cfu/m^3

bus line without opened exhaust ventilation fans, $p<0.01$, $p<0.005$ and $p<0.0005$, depending on the studied bus line (Table 2). In addition, 60 air samples collected from the 12 open-air buses used as another comparison group were analyzed. The mean ± SD of the bacterial or fungal counts was higher than that in the studied air-conditioned buses with and without opened exhaust ventilation fans for each bus line, as shown in Table 2.

When the microbial air quality was described in details by comparison with the level of guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH), it was found that 4.6% of the air samples collected from the studied buses without opened exhaust ventilation fans had high levels of bacterial counts or fungal counts (>500 cfu/m^3). Whereas, there were no air samples collected from the studied buses with opened exhaust ventilation fans having high levels of bacterial or fungal counts (>500 cfu/m^3). Approximately, 98% of the air samples collected from the studied buses with opened exhaust ventilation fans had microbial counts less than 300 cfu/m^3, compared to 79.1% of those collected from the studied buses without opened exhaust ventilation fans. Details are shown in Table 3.

Microbial air quality before and after opening the exhaust ventilation fans in the studied buses

The microbial air quality in the buses with opened exhaust ventilation fans (17 buses, 85 in-bus air samples) were analyzed to compare the microbial counts between before and after opening the exhaust ventilation fans. The results show that the mean ± SD of microbial counts after opening the exhaust ventilation fans were

Table 4
Mean and standard deviation of microbial counts in in-bus air samples: comparison between before and after opening exhaust ventilation fans.

Bus number	No. of studied buses	$\overline{X} \pm$ SD of microbial counts (cfu/m^3)			
		Bacterial counts		Fungal counts	
		Before	After	Before	After
16	7	138.6 ± 94.3	49.1 ± 29.6	40.0 ± 12.9	15.0 ± 5.4
63	4	206.0 ± 119.1	76.5 ± 28.9	92.5 ± 74.6	41.9 ± 29.7
67	4	167.5 ± 91.9	52.7 ± 21.1	65.0 ± 17.3	30.6 ± 13.9
166	2	135.0 ± 21.2	100.0 ± 32.5	70.0 ± 14.1	30.0 ± 13.1
Total	17*	158.3 ±166.9 [a]	68.3 ± 33.8 [a]	85.3 ± 71.2[b]	28.3 ± 19.3[b]

[a] Statistical significance , $p<0.005$; [b] Statistical significance , $p<0.005$

* Eighty-five in-bus air samples were analyzed.

significantly lower than those before opening the exhaust ventilation fans, $p<0.005$ (68.3 ± 33.8 cfu/m^3 *vs* 158.3 ± 166.9 cfu/m^3 for bacterial counts and 28.3 ± 19.3 cfu/m^3 *vs* 85.3 ± 71.2 cfu/m^3 for fungal counts, respectively). Details for each bus line are shown in Table 4.

DISCUSSION

Bacteria in indoor air do not generally present a health hazard, as the flora is usually dominated by gram-positive inhabitants of the skin and upper respiratory passages. However, high counts of bacteria indicate overcrowding and poor ventilation (Seitz, 1989; Kodoma and McGee, 1996). The American Conference of Governmental Industrial Hygienists (ACGIH) Committee suggested that total bacterial or fungal levels in excess of 500 cfu/m^3 in an office workplace were indicative of poor ventilation, overcrowding, and in need of remedial action (Seitz, 1989). For individuals with immunosuppression, the microbial air contamination should be less than 100 cfu/m^3, which can be found in well-ventilated facilities without significant sources and the microbial counts in the general workplace should be less than 300 cfu/m^3 (Burge, 1987; WHO, 1990). Kodama and McGee (1996) reported that persons residing in air-conditioned homes may have a higher frequency of respiratory complaints than those living in naturally ventilated homes.

In order to cover the real situation of microbial air quality in each studied bus, in-bus air samples from 5 points in each studied bus during the cycle of the bus route were collected. A previous study in the same bus line showed 115.2 ± 136.0 cfu/m^3 to 244.7 ± 234.8 cfu/m^3 bacterial counts and 18.8 ± 39.4 cfu/m^3 to 96.1 ± 234.8 cfu/m^3 fungal counts, depending on the studied bus number. Bus numbers 16 and 67 had relatively higher bacterial counts than bus numbers 63 and 166. Whereas, bus number 166 had a relatively higher fungal count than the other bus numbers. In addition, 33% of the studied air-conditioned buses (12/36 buses) had at least 1 point of the in-bus air sample with a high bacterial or fungal count (>500 cfu/m^3) (Luksamijarulkul *et al*, 2004). These findings were given at a meeting of bus drivers. They discussed and agreed with the recommended interventions, including the cleaning program of in-bus environments and air conditioners and the opening of the exhaust ventilation fans during the cycle of the bus route. However, the opening of the exhaust ventilation fans in air-conditioned buses was implemented by voluntary participation of bus drivers. Data from interviews demonstrated that none of the bus drivers had ever opened the exhaust ventilation fans before the beginning of the study. One month after the recommended interventions were given to the bus drivers of the Seventh Bangkok Mass Transit Bus Zone, the researchers observed the opening of the exhaust ventilation fans in each studied bus under real conditions of the bus route, and in-bus air samples were collected to assess the microbial air quality. The present study showed 43.6% of the studied buses (17/39 air-conditioned buses) had opened exhaust ventilation fans during the cycle of the bus route and 56.4% did not. The means of bacterial and fungal counts in the buses with opened ventilation fans were lower than those in the buses without opened exhaust ventilation fans and those in the previous study. In addition, none of air samples collected from the studied buses with opened exhaust ventilation fans were higher than the guideline level (>500 cfu/m^3) compared with 4.6% of the air samples collected from the studied buses without opened exhaust ventilation fans, and 8.9% of the air samples reported in the previous study (Luksamijarulkul *et al*, 2004).

When we compared the microbial counts of the in-bus air samples collected before and after opening the exhaust ventilation fans in the same bus, they showed that the mean microbial counts (bacterial and fungal counts) after opening the exhaust ventilation fans was significantly lower than that before opening the exhaust ventilation fans, $p<0.005$. These findings supported that opening the exhaust ventilation fans could reduce the microbial counts in the studied buses. They may also reduce other air-borne contaminants, including volatile organic compounds (VOCs) and gasoline vapor, which directly or indirectly affects health (Meychting *et al*, 1998; Oliver and Shackleton, 1998; Raaschou-Nielson *et al*, 2001; Lee *et al*, 2002). This intervention is simple and easy to implement because it does not require more resources or skills. It will extend implement in other bus zones of the Bangkok Mass Transit Authority.

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REFERENCES

Burge S. Sick building syndrome: a story of 4373 office workers. *Am Occup Hyg* 1987;31: 493-504.

Hansen SJ. Managing indoor air quality. GA: The Fairmont Press, 1991: 1-10.

Kodama AM, Mc Gee RII. Airborne microbial contaminants in indoor environments naturally ventilated and air-conditioned homes. *Arch Environ Health* 1996; 144: 302-11.

Lee CC, Chen MR, Shih TS, Tgai PJ, Lai CH, Liou SH. Exposure assessment on volatile organic compounds (VOCs) for Tollway station workers via direct and indirect appoaches. *J Occup Health* 2002; 44: 294-300.

Luksamijarulkul P, Sundhiyodhin V, Luksamijarulkul S, Kaewboonchoo O. Microbial air quality in mass transport buses and work-related illness among bus drivers of Bangkok Mass Transit Authority. *J Med Assoc Thai* 2004; 87: 697-703.

Mendell MJ, Smith AH. Consistent pattern of elevated symptoms in air-conditioned office building: a reanalysis of epidemiologic studies. *Am J Public Health* 1990; 80: 1193-9.

Meychting M, Svensson D, Ahlbom A. Exposure to motor vehicle exhaust and childhood cancer. *Scand J Work Environ Health* 1998; 24: 8-11.

Nelson HS, Skufca RM. Double-blind study of suppression of indoor fungi and bacteria by the priclyne biogenic air purifier. *Am Allergy* 1991; 66: 263-6.

Oliver LC, Shackleton BW. The indoor air we breathe. *Public Health Rep* 1998; 113: 398-409.

Raaschou-Nielsen O, Hertel O, Thomsen BL, Olsen JH. Air pollution from traffic at the residence of children with cancer. *Am J Epidemiol* 2001; 153: 433-43.

Riley RL, Nardell EA. Clearing the air: the theory and application of ultra violet air disinfection. *Am Rev Respir Dis* 1989; 139: 1286-94.

Seitz TA. NIOSH indoor air quality investigations 1971-1988. In: Weekes DM, Gammage RB. Proceedings of the indoor air quality, international symposium: the practitioner's approach to indoor air quality investigations. American Industrial Hygiene Association Ohio 1989: 163-71.

World Health Organization. Indoor air quality: biological contaminants. *QHO regional publications. European Ser* 1990; 30: 385-74.

Zweers T. Health and indoor climates complaints of 7043 office workers in 61 building in the Natherlands. *Indoor Air* 1992; 2: 127-36.