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Fluoridation of water supplies and cancer mortality
III: A re-examination of mortality in cities in the USA

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Differences in trends in crude mortality rates from cancer between 10 fluoridated and 10 non-fluoridated cities in the USA were claimed by Yiamouyiannis and Burk to indicate that cancer mortality had risen to an unusual extent in the fluoridated cities.[1 2] These claims, which were widely publicised, prompted us, among others, to examine all relevant published data for the cities in question. When, however, account was taken of the demographic differences between the two groups of cities and the way they changed, there was no suggestion of a greater rise in cancer mortality rates (standardised by the indirect method) in the fluoridated than in the non-fluoridated cities.[3 4] Later Yiamouyiannis and Burk reported that their earlier claim was supported by unpublished data obtained from the vital statistics offices and health departments of the cities concerned when the direct method was used to standardise the mortality rates.[5] In this analysis, however, men and women and whites and non-whites were classed together in broad age groups (0–24, 25–44, etc.) and this analysis did not take account of the changes in the sex and ethnic structure of the populations under comparison or adequate account of changes in their age structure. Although these shortcomings were repeatedly pointed out,[6–8] the claims of Yiamouyiannis and Burk have continued to be published in many parts of the world and extreme statements made about the merits of the direct over the indirect method of standardisation—even when the former is used, as in this case, in a crude and inappropriate manner. Indeed, official inquiries have been instigated in several places including Victoria (Australia) and Minnesota and Kansas (USA).

Through the National Center for Health Statistics, we have now obtained the numbers of deaths from cancer in the cities concerned by sex, ethnic group, and 10-year age group for 1970 so that the direct method of standardisation can be applied properly and the results compared with those obtained by the indirect method. We have also analysed the data for all three census years, 1950, 1960, and 1970, in a variety of alternative ways and in addition have used what, in our opinion, is a more appropriate set of control cities in the analysis.

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Results

In Table 1(a) are shown the ratios of observed to expected numbers obtained when the US national mortality rates for each of the census years 1950, 1960, and 1970 are used as the standard rates and applied successively to the populations of the 10 fluoridated and the 10 non-fluoridated cities (set 1) chosen by Yiamouyiannis and Burk. Whichever rates are used the results are the same, with no indication of a greater deterioration of the situation in the fluoridated cities than in the non-fluoridated cities. When mortality rates are used for the same years as those of the observed numbers, from 1950 to 1970, the observed to expected ratios fell *more* in the fluoridated than in the non-fluoridated cities. When the same mortality rates are used throughout, the ratios increased with time over the period 1950 to 1970 in each case, but by a smaller percentage in the fluoridated cities than in the non-fluoridated cities irrespective of whether the 1950, 1960, or 1970 US rates were used as the standard.

EXCLUSION OF ATLANTA AND SEATTLE

Inclusion of Atlanta and Seattle in the group of non-fluoridated cities has been criticised by Yiamouyiannis because their water supplies began to be fluoridated in the period December 1969 to October 1970 (notwithstanding the fact that two of their control cities, San Diego and Kansas (Missouri), were also fluoridated for a short period, in 1952–4 and 1962–4 respectively). We retained them in the group, however, in order to compare the same two groups as Yiamouyiannis and Burk had compared,

Table 1 *Observed to expected ratios and observed numbers of deaths in fluoridated (F) and non-fluoridated (NF) cities, using different US mortality rates to calculate expected numbers*

		OBSERVED TO EXPECTED RATIOS (observed numbers)			
(a) Non-fluoridated cities (set 1)					
Rates used in calculation of expected number		*1950*	*1960*	*1970*	*Change 1950–70 (per cent)*
Same year	F	1·2302 (21 485)	1·2289 (23 663)	1·1754 (23 405)	−4·45
	NF	1·1509 (11 257)	1·1141 (13 094)	1·1210 (14 272)	−2·60
1950 rates	F	1·2302 (21 485)	1·2420 (23 663)	1·2441 (23 405)	+1·13
	NF	1·1509 (11 257)	1·1202 (13 094)	1·1725 (14 272)	+1·88
1960 rates	F	1·2212 (21 485)	1·2289 (23 663)	1·2284 (23 405)	+0·59
	NF	1·1465 (11 257)	1·1141 (13 094)	1·1650 (14 272)	+1·61
1970 rates	F	1·1694 (21 485)	1·1743 (23 663)	1·1754 (23 405)	+0·51
	NF	1·1003 (11 257)	1·0689 (13 094)	1·1210 (14 272)	+1·88
(b) Excluding Atlanta and Seattle from set 1 of non-fluoridated cities					
Same year	F	1·2302 (21 485)	1·2289 (23 663)	1·1754 (23 405)	−4·45
	NF	1·1457 (9 835)	1·1204 (11 264)	1·1239 (12 229)	−1·90
1950 rates	F	1·2302 (21 485)	1·2420 (23 663)	1·2441 (23 405)	+1·13
	NF	1·1457 (9 835)	1·1261 (11 264)	1·1750 (12 229)	+2·56
1960 rates	F	1·2212 (21 485)	1·2289 (23 663)	1·2284 (23 405)	+0·59
	NF	1·1420 (9 835)	1·1204 (11 264)	1·1679 (12 229)	+2·27
1970 rates	F	1·1694 (21 485)	1·1743 (23 663)	1·1754 (23 405)	+0·51
	NF	1·0962 (9 835)	1·0750 (11 264)	1·1239 (12 229)	+2·53
(c) Non-fluoridated cities (set 2)					
Same year	F	1·2302 (21 485)	1·2289 (23 663)	1·1784 (23 405)	−4·45
	NF	1·1158 (10 456)	1·0779 (12 737	1·0904 (15 121)	−2·28
1950 rates	F	1·2302 (21 485)	1·2420 (23 663)	1·2441 (23 405)	+1·13
	NF	1·1158 (10 456)	1·0845 (12 737)	1·1416 (15 121)	+2·31
1960 rates	F	1·2212 (21 485)	1·2289 (23 663)	1·2284 (23 405)	+0·59
	NF	1·1110 (10 456)	1·0779 (12 737)	1·1332 (15 121)	+2·00
1970 rates	F	1·1694 (21 485)	1·1743 (23 663)	1·1754 (23 405)	+0·51
	NF	1·0674 (10 456)	1·0352 (12 737)	1·0904 (15 121)	+2·15

This table incorporates corrections of errors in our 1977 paper to some of which we have already drawn attention.

and it did not seem reasonable to suspect that such a recent change could have influenced the mortality rates. As it happens, the exclusion of Atlanta and Seattle hardly affects the results at all; but in so far as it does, it serves only to emphasise the slightly greater deterioration of the non-fluoridated cities in comparison with the fluoridated ones over the period 1950 to 1970 (Table 1(b)).

THE SELECTION OF NON-FLUORIDATED CITIES

The cities fluoridated before 1960 that were selected by Yiamouyiannis and Burk were the 10 largest fluoridated cities in the USA. The non-fluoridated cities (as of December 1969) that were selected for comparison were not, however, the largest, but the largest that also had crude cancer death rates in 1953 greater than 155 per 100 000 persons per year. If the selection of the fluoridated group was made on the basis of size, it would have been more consistent if size had been the only criterion for choosing the non-fluoridated cities—even though some of them had lower crude cancer mortality rates in 1953 than the lowest rate observed in the fluoridated cities. Moreover, to select non-fluoridated cities on the basis of their having a high crude cancer death rate is to invite finding a smaller rise than average, because of the general tendency for extreme values to regress towards the mean. We have, therefore, repeated all the analyses using the 10 largest non-fluoridated cities in the USA at the time, as given by Yiamouyiannis and Burk[5] irrespective of their cancer death rate in 1953, viz: Los Angeles, New Orleans, Boston, Columbus, Cincinnati, San Diego, San Antonio, Houston, Memphis, and Kansas City (that is, substituting San Diego, San Antonio, Houston, and Memphis for Atlanta, Newark, Portland, and Seattle).

Table 1(c) shows that the observed to expected ratio of deaths in this second set of non-fluoridated cities tended to rise slightly more over the period 1950 to 1970 than in the set used by Yiamouyiannis and Burk irrespective of whether the 1950, 1960, or 1970 national mortality rates were used to calculate the expected rates throughout. Alternatively, if the same year's mortality rates are used in the census years the fall in the rate is slightly less. In sum, the changes in these 10 non-fluoridated cities from 1950 to 1970 weigh very slightly more heavily against the claims of Yiamouyiannis and Burk[2 5] than those in the 10 cities that they chose for comparison.

The populations by sex, age, and ethnic group of the different groups of cities are shown in Appendix

Appendix Table A *Populations of different groups of fluoridated and non-fluoridated US cities by age group, sex, and ethnic group*

Age groups (years)	Sex and ethnic group	Fluoridated cities			10 largest non-fluoridated cities (set 1)			Non-fluoridated cities excluding Atlanta and Seattle			10 largest non-fluoridated cities (set 2)		
		1950	1960	1970	1950	1960	1970	1950	1960	1970	1950	1960	1970
0–4	WM	445699	393889	241330	248605	274063	200470	218733	237040	177538	267851	338345	266126
	WF	427866	380592	231340	239646	263860	191374	210541	228220	169882	259215	325764	255350
	NM	104708	214572	200235	46664	98299	105627	38434	82373	88786	51863	107632	112442
	NF	104153	215591	199492	45978	98103	105293	37828	81852	88614	51268	107342	112195
5–14	WM	619757	645003	516548	333387	463286	427787	295510	397199	379673	353688	556216	583907
	WF	606245	626892	499238	326362	451064	412852	288747	385926	366891	345585	542550	563801
	NM	142034	308868	455728	62101	140209	223574	51375	115911	187635	68466	153200	244153
	NF	145091	312069	458431	63073	142451	223754	52205	117523	187432	70396	154925	244891
15–24	WM	652084	523439	546952	350159	353666	472949	303627	298239	407184	368286	427625	618269
	WF	697423	576574	595390	382375	389867	515759	335371	329968	444119	396770	438005	634462
	NM	130152	171539	316332	57244	84625	160833	46362	69467	131700	62876	91083	175242
	NF	159258	210317	377494	69713	100997	191736	56557	83221	157053	76863	106169	202802
25–34	WM	817903	536041	419590	439784	366718	355673	385426	315852	307108	456858	432692	443764
	WF	867056	508108	403659	465069	356846	341463	409032	309242	298620	480065	427142	435104
	NM	174359	206610	227878	75938	99101	124685	63314	83751	102921	81385	103708	128976
	NF	203117	243484	281199	87173	112365	146220	72227	94202	121920	93189	117915	151173
35–44	WM	738551	548090	347741	395845	373838	289135	348436	320722	254125	398036	426335	371554
	WF	796568	598369	351210	429908	402897	293002	378714	345107	258872	429697	450783	382087
	NM	155869	198535	207143	69468	91411	100659	57482	76944	84562	74373	95074	106803
	NF	166864	219656	251173	74816	100838	119966	61531	84062	100781	81500	104610	127653
45–54	WM	651109	552478	409401	346616	344119	309581	306290	293148	267357	335468	362038	374607
	WF	681994	613891	471011	371962	379779	345673	328719	324125	298204	359948	395871	411394
	NM	121451	150421	183232	51555	69904	85926	43480	57804	72279	57049	73183	91275
	NF	113717	156619	209000	51530	73776	100069	42500	60803	83862	56912	78358	105073
55–64	WM	540458	471999	390757	273478	279107	259072	240724	240326	221274	251067	279313	287624
	WF	547086	527141	473795	300240	324218	312346	265351	279369	266831	280338	325062	342890
	NM	63064	104577	126331	28230	46829	61144	23847	39372	50621	31745	50558	65884
	NF	58352	103238	144077	27667	49915	71592	23073	41338	59442	30546	53421	77085
65–74	WM	286452	321441	251194	161214	188786	162162	141187	162830	139828	145487	180250	173889
	WF	329838	393159	362169	204045	249770	243678	180560	215800	209585	190764	241738	258945
	NM	30237	50964	74824	15923	25043	35408	13316	20933	29740	17753	27928	39865
	NF	33703	55662	89990	17818	29096	46095	14760	24042	38189	20353	31962	50553
75–84	WM	89563	111081	117563	56004	74041	75634	49377	63074	65032	51611	69027	76954
	WF	127440	159420	196270	84760	115907	138858	75450	99548	118841	80331	111631	141735
	NM	7916	15786	23811	4274	8890	12201	3565	7374	10350	4923	9688	14055
	NF	10094	19813	32888	5165	10646	17861	4223	8905	14878	5979	11852	19827
85+	WM	12444	16082	22468	8601	12240	17313	7563	10462	14763	8003	11768	17169
	WF	22553	31294	44248	15768	25101	36483	14148	21782	31164	15037	24533	37577
	NM	1279	2895	5921	681	1599	3396	567	1336	2828	797	1855	3874
	NF	2237	4504	9579	1238	2310	5428	1020	1846	4443	1419	2676	6116
		11 885 744	11 500 703	10 766 632	6 290 077	7 075 580	7 342 731	5 491 172	6 031 038	6 314 927	6 413 760	7 849 827	8 757 145

WM = white males
WF = white females
NM = non-white males
NF = non-white females

Table A—the 10 fluoridated cities, the non-fluoridated cities (set 1) both including and excluding Atlanta and Seattle, and the 10 largest non-fluoridated cities (set 2). The US national cancer mortality rates for 1950, 1960, and 1970 are shown in Appendix Table B by sex, age, and ethnic group.

COMPARISON OF DIRECT AND INDIRECT METHODS OF STANDARDISING MORTALITY RATES

Yiamouyiannis and Burk have claimed that the indirect method of standardising cancer death rates in the two sets of cities in the USA was less appropriate than the direct method which they came to use, notwithstanding that, in their use, they classed both sexes and both ethnic groups together and used broad 20-year age groups. Reasons have been given repeatedly elsewhere for dismissing this claim. It is, however, now possible to compare the results of the direct and indirect methods using equally detailed data for both. Through the good offices of the US National Center for Health Statistics we have

Appendix Table B *Cancer mortality rates by age, sex, and ethnic group for the US in 1950, 1960, and 1970 and the rates in groups of fluoridated and non-fluoridated cities*

Age groups (years)	Sex and ethnic group	US CANCER MORTALITY RATES 1950	1960	1970	1970 US POPULATION (thousands)	CANCER MORTALITY RATES Fluoridated cities Rate	No.	Non-fluoridated cities (set 1) Rate	No.	Non-fluoridated (set 1) excluding Atlanta and Seattle Rate	No.	Non-fluoridated (set 2) Rate	No.	1970 pooled rates for fluoridated and non-fluoridated cities (set 1)
0–4	WM	12·4	12·0	7·7	7 374·3	7·04	17	8·98	18	7·32	13	7·14	19	7·9
	WF	10·6	9·1	6·6	7 048·8	8·65	20	8·36	16	5·89	10	8·22	21	8·5
	NM	8·7	7·8	6·6	1 371·2	5·99	12	8·52	9	6·76	6	5·34	6	6·9
	NF	7·1	6·9	5·1	1 360·0	6·02	12	3·80	4	4·51	4	4·46	5	5·2
5–14	WM	7·6	8·0	7·0	17 666·8	7·36	38	6·55	28	6·32	24	6·17	36	7·0
	WF	6·3	6·2	5·4	16 911·7	5·41	27	5·57	23	6·27	23	7·09	40	5·5
	NM	5·7	4·9	5·0	3 092·4	5·92	27	5·81	13	6·40	12	6·14	15	5·9
	NF	4·0	4·8	3·9	3 074·8	3·49	16	1·79	4	1·60	3	3·27	8	2·9
15–24	WM	9·9	10·3	10·6	15 232·1	8·96	49	12·47	59	12·77	52	10·35	64	10·6
	WF	7·5	6·5	6·2	15 420·1	5·71	34	5·82	30	6·53	29	6·46	41	5·8
	NM	7·7	9·2	9·0	2 319·0	10·75	34	11·81	19	12·15	16	9·13	16	11·1
	NF	8·6	6·7	6·2	2 470·2	6·62	25	5·22	10	5·09	8	5·42	11	6·1
25–34	WM	17·7	18·8	16·2	10 774·9	16·68	70	14·90	53	14·65	45	15·32	68	15·9
	WF	20·9	18·8	16·3	11 004·5	14·37	58	15·81	54	16·07	48	16·32	71	15·0
	NM	17·9	18·2	17·1	1 442·5	16·68	38	24·86	31	23·32	24	20·16	26	19·6
	NF	33·5	29·6	19·6	1 885·6	17·43	49	21·88	32	21·33	26	19·84	30	19·0
35–44	WM	44·5	46·3	50·1	9 978·9	64·42	224	60·87	176	62·17	158	58·67	218	62·8
	WF	74·5	66·6	62·4	10 348·8	69·19	243	80·55	236	79·58	206	69·88	267	74·4
	NM	56·0	71·7	76·0	1 252·4	95·10	197	109·28	110	105·25	89	97·38	104	99·7
	NF	119·3	98·3	87·5	1 507·7	89·98	226	95·86	115	95·26	96	98·71	126	91·9
45–54	WM	150·8	164·1	172·0	10 090·2	223·74	916	194·13	601	191·88	513	186·60	699	211·0
	WF	185·8	175·7	177·3	10 756·3	228·02	1074	205·40	710	200·20	597	192·27	791	218·4
	NM	207·4	233·6	288·2	1 109·1	349·28	640	339·83	292	343·11	248	325·39	297	346·3
	NF	273·3	249·3	217·1	1 264·4	244·98	512	231·84	232	228·95	192	220·80	232	240·7
55–64	WM	409·4	450·9	498·1	7 958·2	616·24	2408	579·39	1501	580·28	1284	545·50	1569	601·5
	WF	362·5	329·0	338·6	8 853·0	379·49	1798	393·15	1228	396·51	1058	382·05	1310	384·9
	NM	484·8	549·8	642·9	834·6	822·44	1039	711·44	435	728·95	369	695·16	458	786·2
	NF	481·0	427·8	387·1	944·0	441·43	636	451·17	323	462·64	275	482·58	372	444·7
65–74	WM	798·7	887·3	997·0	4 915·5	1218·58	3061	1110·00	1800	1091·34	1526	1084·02	1885	1176·0
	WF	616·5	562·1	554·7	6·365·6	643·62	2331	602·84	1469	609·30	1277	593·56	1537	627·2
	NM	632·7	927·5	1099·2	521·6	1288·36	964	1160·75	411	1186·95	353	1184·00	472	1247·4
	NF	476·9	537·6	589·6	632·8	654·52	589	609·61	281	617·98	236	648·82	328	639·3
75–84	WM	1367·6	1413·7	1592·7	2 243·2	1849·22	2174	1763·76	1334	1743·76	1134	1678·93	1292	1815·8
	WF	1026·6	939·3	903·5	3 429·2	1007·80	1978	1003·18	1393	1011·44	1202	991·29	1405	1005·9
	NM	844·4	1086·1	1536·9	193·1	1805·89	430	1704·78	208	1816·43	188	1700·46	239	1771·6
	NF	578·9	702·3	734·7	253·7	817·93	269	761·44	136	752·79	112	726·28	144	798·0
85+	WM	1732·7	1791·4	1772·2	487·0	2011·75	452	1854·10	321	1889·86	279	1881·30	323	1943·1
	WF	1348·3	1304·9	1126·6	889·9	1240·73	549	1227·97	448	1264·28	394	1248·10	469	1235·0
	NM	916·0	1211·7	1268·4	55·4	1435·57	85	1766·78	60	1944·84	55	1626·23	63	1556·3
	NF	716·0	727·5	758·9	78·7	876·92	84	902·73	49	1012·83	45	719·42	44	886·3
TOTAL					203 211·9		23405		14272		12229		15121	
Standardised rate (1970 US population)						189·80		180·69		180·65		175·19		

WM = white males
WF = white females
NM = non-white males
NF = non-white females

FLUORIDATED CITIES: San Francisco, Washington DC, Chicago, Baltimore, St. Louis, Buffalo, Cleveland, Philadelphia, Pittsburgh, Milwaukee.
NON-FLUORIDATED CITIES (set 1): Los Angeles, Boston, Kansas City, Atlanta, Newark, Cincinatti, Portland, Seattle, New Orleans, Columbus.
NON-FLUORIDATED CITIES (set 2): Los Angeles, New Orleans, Boston, Columbus, Cincinnati, San Diego, San Antonio, Houston, Memphis, Kansas (Missouri).

Table 2 *Comparison of mortality ratios (indirectly standardised) with directly standardised cancer mortality rates for both fluoridated and non-fluoridated cities in 1970*

	Indirect	*Direct*
Fluoridated / Non-fluoridated (set 1)	$\frac{1{\cdot}18}{1{\cdot}12} = 1{\cdot}05$	$\frac{189{\cdot}80}{180{\cdot}69} = 1{\cdot}05$
Fluoridated / Non-fluoridated (set 1) excluding Atlanta and Seattle	$\frac{1{\cdot}18}{1{\cdot}12} = 1{\cdot}05$	$\frac{189{\cdot}80}{180{\cdot}65} = 1{\cdot}05$
Fluoridated / Non-fluoridated (set 2)	$\frac{1{\cdot}18}{1{\cdot}09} = 1{\cdot}08$	$\frac{189{\cdot}80}{175{\cdot}19} = 1{\cdot}08$

obtained the numbers of deaths from cancer in all of the cities concerned by sex, ethnic group, and 10-year age group in 1970 (Appendix Table B) and so we have been able to use the direct method of standardisation in an adequate way. No anomalies were evident in an examination of the age, sex, and ethnic group specific mortality rates recorded for each group of cities. These rates have been used to calculate the numbers of deaths that would have occurred in the entire United States of America if the population had experienced the same rates. By using the rates shown in Appendix Table B and the corresponding populations for 1970 in Appendix Table A, we have obtained directly standardised rates for comparison with those obtained by the indirect method. The results, which are shown in Table 2, are identical. It was not possible to obtain corresponding data for the other two census years, 1950 and 1960, because the National Center for Health Statistics no longer held the basic data.

CALCULATION OF SMRs USING POOLED DATA FOR 20 CITIES

It is also now possible to use the pooled experience of the two sets of cities to constitute the standard population for the calculation of standardised mortality ratios by the indirect method. In this way we can examine the effect of our earlier use of national data as standards for comparing the mortality in sets of cities that were not typical of the country as a whole. The pooled mortality rates are shown in Appendix Table B and the results obtained by using them are shown in Table 3. The results show clearly and incontrovertibly that the mortality rates are almost identical in the two sets of cities when sex, age, and ethnic group are taken into account, and that the very slight excess in the fluoridated cities is proportionately less in 1970 than in 1950. Our conclusion is unaltered. The ideal comparison would require the use of pooled mortality rates in 1950 to calculate the expected numbers of deaths in 1950 and the pooled rate in 1960 to calculate the expected numbers in 1960, but unfortunately these are now irretrievable.

Conclusion

The mortality from cancer in the 10 largest cities in the USA that have had fluoridated water supplies since before 1957 was somewhat higher in 1970 than in the large non-fluoridated cities that we have examined. The relative excess has not increased since 1950, if allowance is made for changes in the sex, age, and ethnic group constitution of the population by any of the standard methods. On the contrary, it has

Table 3 *Expected numbers and observed to expected ratios using pooled cancer mortality rates in 1970 for the original 20 cities*

	Fluoridated	*Non-fluoridated set 1 (including Atlanta and Seattle)*	*Non-fluoridated set 1 (excluding Atlanta and Seattle)*	*Non-fluoridated set 2*
50 Observed	21 485	11 257	9 835	10 456
expected	21 394	11 890	10 426	11 378
ratio	1·0043	0·9468	0·9433	0·9190
60 Observed	23 663	13 094	11 264	12 737
expected	23 388	14 195	12 141	14 259
ratio	1·0118	0·9224	0·9278	0·8933
70 Observed	23 405	14 272	12 229	15 121
expected	22 985	14 692	12 557	16 016
ratio	1·0183	0·9714	0·9739	0·9442
Increase of ratio	$\frac{0{\cdot}0140}{1{\cdot}0043} = 1{\cdot}39\%$	$\frac{0{\cdot}0246}{0{\cdot}9468} = 2{\cdot}60\%$	$\frac{0{\cdot}0306}{0{\cdot}9433} = 3{\cdot}24\%$	$\frac{0{\cdot}0252}{0{\cdot}9190} = 2{\cdot}74\%$

decreased slightly no matter which of the appropriate methods of comparison is chosen.

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