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Review

# Sellafield and Other Clusters of Childhood Cancer in the Vicinity of Nuclear Installations

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A media report in 1983 drew attention to high levels of childhood leukaemia around the Sellafield nuclear reprocessing plant. This prompted investigations around other nuclear installations, some of which suggested other "clusters", though Sellafield remained the most striking. Many studies over more than 30 years have investigated possible reasons for such clusters. Inevitably attention was first directed at radiation linked with activities at the plant. However, it was found that doses from accidental and planned releases were too low to account for the observed levels of childhood leukaemia. Various other mechanisms involving radiation have been investigated and have also been discounted. While no clear explanation for the Sellafield cluster has been found, perhaps the most plausible remaining hypothesis involves "population mixing" in which an infection is spread to susceptible individuals and, in rare cases, results in leukaemia.

*Key words:* Childhood cancer, leukaemia, clusters, nuclear installations, Sellafield

## 1. Introduction

On 1 November 1983 a programme "Windscale – The Nuclear Laundry" made by the Yorkshire Television Company was shown on the British television channel, ITV. It claimed that there was a substantial excess incidence of cancer in children and young people in the area around what is now called the Sellafield nuclear reprocessing plant. In particular it claimed a ten-fold excess of leukaemia among children aged under 10 years. One of the authors remembers speaking to a consultant to the programme who remarked approvingly of "the genius" of the programme makers in ensuring that no premature word of the claims leaked out so that

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the broadcast had maximum effect. This it certainly did. There was wide-spread and deep public concern, especially of course amongst those living in the area, particularly in the local village of Seascale. It was suggested that excess childhood cancer might be a consequence of emissions from the Sellafield plant which released radioactivity into the environment in normal operation but which had also generated some accidental releases[1], most notably during the Windscale Fire of 1957 (Windscale being a previous name for the plant)[2].

The British government set up an expert Advisory Committee under the Chairmanship of Sir Douglas Black to investigate the claims. It worked with astonishing speed by the current standards of such bodies and published its report in July 1984[3]. The Black report was cautious in its conclusions, but confirmed that there did appear to be high levels of leukaemia in those aged up to 24 years. However, the estimated radiation doses to the local population were too low to account for the observed leukaemia incidence using accepted values for relevant dose coefficients. The Black Committee recommended additional scientific investigations of the apparent excess and of the radiation doses incurred by members of the public in the area.

Not long after the publication of the conclusions of the Black Committee, a paper was published in 1986 reporting an excess of childhood leukaemia in the vicinity of the Dounreay nuclear plant in Northern Scotland[4]. Dounreay is the other nuclear plant in Britain where nuclear fuel is reprocessed and inevitably it was suggested that there was a causal link between some aspect of the activities at the two plants and childhood cancer in surrounding areas.

Concern did not stop at nuclear reprocessing plants and studies were carried out to investigate rates of childhood and other cancers around all kinds of nuclear installations, including nuclear power plants all over the world. One of the earliest British publications was the 1987 review by Cook-Mozaffari and co-workers[5, 6] of cancer mortality near nuclear installations in England and Wales 1959-1980. This concluded that there had been no general increase; childhood leukaemia might be an exception, but no reason for such an increase, if real, could be suggested.

Taken altogether, the literature on clusters is formidable. An authoritative 2008 review by Laurier *et al.*[7], restricted to childhood leukaemia, considered "several hundred publications". Care is needed in the interpretation of these studies. There can be considerable variation in exactly what is being considered:

What is the age range? (0-14 or 0-24 are common choices but others are possible)

What is the disease grouping (Leukaemia? Leukaemia and Non-Hodgkin Lymphoma? All cancers? ⋯)

What area and time-period are being studied?

What is the definition of a relevant case (Born in the area? Diagnosed in the area?)

Nowadays studies will normally be of incidence, but mortality studies will also be encountered

An apparently noteworthy excess can sometimes be a result of choosing the parameters so as to include the maximum number of cases, but as few other individuals as possible (the "Texas Sharpshooter Fallacy"). A further caveat in the interpretation of these studies is that many nuclear facilities have been investigated and thus chance findings of excesses are to be expected and publication bias is also likely. Nevertheless, some cancer clusters near nuclear installations certainly exist. As an aside, we note that normal English usage would be that "a cluster" is a reflection of a tendency for cases to be close to one another in space and time. This is not quite the same as an aggregation near a point source which might be a result of some aetiological factor. However, the latter sense is in popular usage and we employ it here.

Laurier *et al.* reported that among 198 sites there were three confirmed clusters meeting the criteria that had been set out.

Seascale near Sellafield (Cumbria, England)

Dounreay (Caithness, Scotland)

Elbmarsch near Kruemmel NPP (Germany)

Other clusters were "not conclusively established". These included areas around Aldermaston and Burghfield (UK) and the La Hague reprocessing plant (France). No excess risk was reported for the large majority of the 198 sites.

In what follows we will concentrate mainly on British nuclear installations and particularly on Sellafield, but a few words on German nuclear power stations are warranted, in particular on the 2008 KiKK Study[8]. KiKK is an acronym from "Kinderkrebs in der Umgebung von Kernkraftwerken" ie Childhood Cancer in the areas around Nuclear Power Plants. Germany has no nuclear reprocessing plants,

The KiKK study was a case control study involving children up to 5 years of age, diagnosed between 1980 and 2003. The study includes 593 leukaemia cases and 1,766 matched controls (three controls per case). For all leukaemias combined there was a statistically significant trend for increasing risk with inverse distance from the nearest nuclear power plant. There was a statistically significant odds ratio of 2.19 for residential proximity within 5 km compared to residence outside this area. The authors noted that such findings were not to be expected on the basis of our understanding of radiation protection and they could offer no explanation. We contrast this study with British findings below.

In this paper we discuss investigations of clusters of childhood cancer around nuclear installations with especial attention to Sellafield. A summary of the chronology is in Table 1.

**Table 1.** Chronology of some events in the investigation of the Sellafield Cluster

| Year | Month | Event | ref |
|---|---|---|---|
| 1957 | Oct | Windscale Fire | 2) |
| 1983 | Nov | Yorkshire TV programme reports suggestions of high levels of cancer around Sellafield | 3) |
| 1983 | Nov | First meeting of the Black Committee | 3) |
| 1984 | Jul | Publication of NRPB-R171 reviewing doses to the population around Sellafield | 9) |
| 1984 | Jul | Publication of Black Report | 3) |
| 1985 | Nov | COMARE set up | 44) |
| 1986 | Feb | Heasman *et al.* report Dounreay cluster in The Lancet | 4) |
| 1986 | July | Publication of COMARE's first report (on Sellafield) | 44) |
| 1988 | | Greaves and Kinlen suggest that an infective mechanism may be important in childhood leukaemia | 33, 35) |
| 1990 | Feb | Gardner suggests that paternal preconceptional irradiation may be a cause of childhood leukaemia | 20) |
| 1993 | Jan | Draper *et al.* (BMJ) confirm Seascale cluster 1963-1983 and report continuation to 1990 | 11) |
| 1993 | Oct | Judgement against Reay and Hope in their case against BNFL relating to alleged radiation induced cancer | 45) |
| 1994 | Aug | Bithell *et al.* survey LNHL incidence around British nuclear installations | 12) |
| 1995 | Oct | Publication of NRPB-R276 reviewing risks and doses to the Sellafield cohort | 10) |
| 1996 | Mar | Publication of COMARE's Fourth report on cancers in the vicinity of Sellafield | 26) |
| 1997 | Nov | Draper *et al.* (BMJ) report that the Record Linkage Study does not support the Gardner Hypothesis | 21) |
| 2005 | Jun | Publication of COMARE's 10th report on the incidence of childhood cancer around nuclear installations in Britain | 13) |
| 2008 | Feb | KiKK study published (Kaatsch *et al.*) | 8) |
| 2011 | May | Publication of COMARE's 14th report on childhood cancer around nuclear power plants | 16) |
| 2013 | Sep | Bithell *et al.* publish a case-control study of childhood cancer around British nuclear installations | 17) |
| 2014 | Jul | Bunch *et al.* extend studies of childhood cancer around Sellafield and Dounreay; no excess seen during 1991-2006 | 18) |

**Table 2.** Relevant Reports published by COMARE

| No. | Date | Brief topic | Ref |
|---|---|---|---|
| 1 | 1986 | Sellafield | 44) |
| 2 | 1988 | Dounreay | 46) |
| 3 | 1989 | Aldermaston and Burghfield | 47) |
| 4 | 1996 | Update on Sellafield | 26) |
| 5 | 1998 | Greenham Common Airbase | 48) |
| 7 | 2002 | PPI and Childhood Cancer | 49) |
| 10 | 2005 | Childhood cancer around Nuclear Installations in GB | 13) |
| 11 | 2006 | Childhood cancer in GB generally | 50) |
| 14 | 2011 | Childhood leukaemia around NPP in GB | 16) |

## 2. The Role of COMARE

In November 1985, in response to the recommendations of the Black Committee, the British Government set up COMARE, the Committee On Medical Aspects of Radiation in the Environment. COMARE has published a number of reports, most of which are relevant to the general area of childhood cancer clusters around nuclear installations; a brief summary is in Table 2. The work of COMARE, as of the Black Committee before it, was supported by a number of other organisations, in particular the Childhood Cancer Research Group and the National Radiological Protection Board (NRPB, later part of the Health Protection Agency and now within Public Health England).

In the present context, the most important of the contributions by the NRPB were two large studies assessing the doses to children living in the vicinity of the Sellafield reprocessing plant. The first of these was published in 1984[9] and was central to the work of the

Black Committee. The second NRPB report, which to a large extent supersedes the former, was published in 1995[10].

Simmonds *et al.*[10] in 1995 estimated the doses from all sources of radiation and subsequent risks of cancer applying the best available models to a cohort of 1348 children born in Seascale during 1945-1992, followed to age 24 or the end of 1992 whichever came first. The doses from nuclear discharges were estimated by modelling and by using environmental monitoring results, the latter being preferred where possible. One of the main conclusions of this study, accepted by COMARE, was that natural radiation contributes 80% of the risk of radiation-induced leukaemia and non-Hodgkin lymphoma ("LNHL"). Non-Hodgkin lymphoma was combined with leukaemia because it was considered plausible that in the early part of the period investigated the differential diagnosis was not necessarily consistent. Since doses from Sellafield discharges were much smaller than those from natural sources it was implausible that they could cause a large local increase in LNHL.

Over 30 years (1984 to 2014) a major part of the work of the Childhood Cancer Research Group (CCRG) was driven by COMARE's work on childhood cancer around nuclear installations. This work made extensive use of the National Registry of Childhood Tumours (NRCT) maintained by CCRG. Some particularly significant developments are described below.

## 3. Environmental Risks around Nuclear Installations

In 1993 Draper *et al.* published a paper[11] confirming the increased childhood leukaemia/LNHL incidence (0-24y) in Seascale between 1963 and 1983. For the first time they demonstrated that an increased risk continued beyond this period and to 1984-90. Draper *et al.* concluded "The increased risk is unlikely to be due to chance but the reasons for it are unknown".

In one of the first comprehensive surveys of LNHL incidence around all nuclear installations (both nuclear power plants and other nuclear installations such as reprocessing, research and defence establishments) in Britain, the 1994 study by Bithell *et al.*[12] found little evidence of elevated incidence in the vicinity of British Nuclear Power Plants. Evidence for clusters around other nuclear installations was stronger, in particular for Sellafield. The analyses of Bithell *et al.*[(12)] were later updated for the 2005 COMARE Tenth Report[13].

The 1994 study by Bithell *et al.* of LNHL around British nuclear installations[12] had used age and disease classifications consistent with British practice. In 2008 Bithell and co-workers published a new study which set out to be as close a parallel to the KiKK study as could be achieved within the constraints of a geographical study[14, 15]; specifically, they examined only children under 5yr. It should be noted that the findings of the German KiKK study were in contrast to the negative 1994 findings around NPP of Bithell *et al.*[12] and the 2005 COMARE Tenth Report[13].

The incidence ratio (IR) for cases of acute leukaemia aged under 5 years within 5 km of a nuclear power plant was not significant: O = 20, E = 14.74, IR = 1.36 (95% Confidence Interval 0.83-2.10). Nor were risk coefficients for proximity in the regression analysis significant. Similar analyses and results were reported in COMARE's 14th report[16], which included a comparative review of the KiKK study.

A yet closer parallel with the KiKK study was published by Bithell *et al.* in 2013[17]. This was a first British case-control study, involving 9821 cases of LNHL at ages 0-5y around British nuclear power plants. No increased risk associated with residential proximity to nuclear power plants was found. Moreover, the risk estimates were incompatible with the German KiKK case–control study.

In 2014 Bunch *et al.* updated the analyses of childhood cancer at ages 0-24 years around Sellafield and Dounreay[18]. The study period was extended from 1963-90 to 2006. The results for 1963 – 1990 were consistent with earlier studies. However, there was no excess of cancers around Sellafield and Dounreay over more recent years (1991–2006). Wakeford suggested that this study might mark the beginning of the end for studies of the Sellafield Cluster[19]. We note, however, that COMARE plans to publish another report reviewing the incidence of childhood leukaemia and other cancers in the vicinity of Sellafield and of Dounreay.

## 4. Parental Preconceptional Irradiation (PPI)

In 1990, Professor Martin Gardner (who had been a member of the Black Committee) and colleagues published the results of a case-control study[20] suggesting that high doses of radiation received by men before they fathered children was associated with LNHL in their offspring. A particularly striking result was a Relative Risk of 6.45 for men who had accumulated a total preconceptional dose exceeding 100 mSv. This offered a novel potential explanation for the Sellafield Cluster which overcame the difficulty that the estimated doses to the children themselves were far too low, on the basis of accepted risk estimates, to account for the observed levels of leukaemia.

A number of investigations were started to explore the Gardner Hypothesis, as it became known. Prominent amongst these were the "Record Linkage Studies" by CCRG/NRPB. These studies were based on identifying parents of cases from the NRCT and matched controls

**Table 3.** Collective doses to red bone marrow and risks of LNHL up to the 25th birthday or to 1992, whichever is sooner, in a cohort of 1348 persons
After COMARE 4th Report[26] table 3.7

| Source | Collective Equivalent Dose (Man Sv) | % of total dose | Predicted incident cases of LNHL |
|---|---|---|---|
| Natural background | 39.04 | 80.6 | 0.36 |
| Fallout | 2.11 | 4.4 | 0.03 |
| Medical | 3.07 | 6.3 | 0.02 |
| Albright and Wilson* | 0.091 | 0.2 | 0.0007 |
| All Sellafield discharges | 3.11 | 6.4 | 0.04 |
| Windscale fire | 0.917 | 1.9 | 0.01 |
| Chernobyl | 0.079 | 0.2 | 0.0003 |
| TOTAL | 48.42 | 100.0 | 0.451 |
| Expected number based on national rates | | | 1.08 |
| Observed number of cases | | | 12 |

*Albright and Wilson Ltd produced phosphates for use in detergents and in doing so discharged liquid effluents containing naturally occurring radionuclides

and ascertaining which were included in the National Registry for Radiation Workers, a large database with details of nuclear workers maintained by NRPB. It was then a matter of comparing the relative numbers of links to the parents of cases and controls and also comparing the doses that the respective parents had incurred.

The first of the Record Linkage Studies[21] found that there was indeed a raised risk of LNHL in the offspring of radiation workers (relative risk 1.77, 95% confidence interval 1.05 to 3.03) but there was no dose-response relation for either of the exposure periods studied (fathers with a lifetime preconception dose of 100 mSv or more, or with a dose in the 6 months before conception of 10 mSv or more). Indeed, the association was greatest for those who were monitored for exposure to radiation but whose doses were below the level of detection. There was no increased risk for the group of other childhood cancers. The result thus did not support the hypothesis that paternal preconception irradiation is a cause of childhood leukaemia and non-Hodgkin lymphoma. The numbers of mothers who had been radiation workers were very small. However, mother's radiation work was associated with an increased risk of childhood cancer (relative risk 5.00, 1.42 to 26.94). The statistical uncertainties were large, but this was a finding flagged for further investigation when more data were available.

Sorahan *et al.*[22] undertook a further analysis of what was essentially the same cohort as that studied by Draper *et al.*[23] However, the focus was now on the timing of employment at the nuclear site in relation to the conception of the children. The conclusion was that risk was restricted to those working at the site at the time of conception of the child. Men did not carry risk away with them after employment as would be expected if some kind of molecular damage to their genetic cells was involved.

Bunch *et al.*[24] studied the mothers of the same cohort together with an additional 16,964 childhood cancer patients taken from the NRCT, together with the same number of matched controls. Pooled analyses, based on the new and original datasets, include 52,612 case and control mothers. The new data provide no evidence of significantly increased risk of childhood cancer with mother's radiation work, nor was there any increased risk in subgroups which might be taken to be at particular risk (higher dose groups, those monitored for internal exposures or women exposed while pregnant). The investigators concluded that neither the new nor the pooled data support suggestions of childhood cancer risks in offspring of female radiation workers.

In a civil lawsuit brought against BNFL in 1992–93 Parental Preconceptional Irradiation was suggested to be the cause (or a material contributory cause) of leukaemia in an infant and non-Hodgkin lymphoma in a young adult[25]. After a trial lasting 90 days the judge found that the evidence was 'decisively' against PPI being responsible.

The hypothesis that Parental Preconceptional Irradiation causes cancer in offspring has now been largely abandoned.

## 5. Possible Explanations for the Sellafield Cluster

We thus have a situation where there is an undoubted cluster of childhood leukaemias in the vicinity of the Sellafield nuclear plant. Inevitably the first thought has been that some aspect of the activities at the plant is responsible.

**Table 4.** Meta-analysis of 17 studies of childhood leukaemia and rural Population Mixing. Relative Risks for various age groups

| Age Group | Relative Risk | 95% Confidence Interval |
|---|---|---|
| 0 - 14y | 1.57 | 1.44 - 1.72 |
| 0 - 4y | 1.72 | 1.54 - 1.91 |
| Below age 2 years | 1.51 | 1.17 - 1.92 |

Data for age groups 0 - 14y and 0 - 4y are from the 2012 publication of Kinlen *et al.*[36] The data for the "below 2 years" age group are from the 2011 publication of Kinlen[51].
These results may be compared with urban areas with similar levels of population mixing
RR at ages 0 - 14 1.00 (0.93 - 1.07)

The first reaction might be to ask whether nuclear discharges from Sellafield could be the cause. However, assessments by the NRPB, reviewed in COMARE's 4th Report[26] found that four fifths of the total dose to the red bone marrow (the organ where leukaemias are thought to originate) was from natural sources, with less than 10% from Sellafield discharges (Table 3). It is quite implausible that such a small contribution to the overall dose could account for a ten-fold increase in risk.

*Perhaps the Sellafield discharges had been underestimated?*
Table 3 also shows that in the Sellafield cohort there were 12 cases of LNHL. The number predicted to be a consequence of radiation of all kinds was less than 0.5, of which the number predicted to be due to all Sellafield discharges (ie both planned and unplanned) was less than 0.05. The discharges would thus have to be about 200 times larger than estimated to account for the fact that twelve cases were observed when only one was expected. If this were the case, the extensive environmental monitoring that has been undertaken round the plant could hardly have failed to pick it up.

*Perhaps radiation is much more dangerous than is believed so that discharges of about the level indicated by the environmental monitoring could result in twelve cases of LNHL?*
As Table 3 shows, doses from natural radiation dominate those from artificial sources and their effects should be easy to detect. The effects of natural radiation can indeed be detected in very large studies, but the risk factor is about that indicated by studies of the atomic bomb survivors and other sources[27].

*Supposing radiation from artificial nuclides in discharges is much more dangerous than radiation from natural radionuclides?*
During the 1950s and 1960s a number of countries carried out testing of nuclear weapons which released considerable quantities of radioactive material into the atmosphere. When this material fell back to the earth's surface it gave rise to "fallout doses" which peaked in the late 1950s to early 1960s. Fallout nuclides are broadly similar to those in nuclear discharges. If these nuclides are particularly dangerous then it would be expected that the effects of weapons testing fallout should be detectable in the form of increased incidence of LNHL after the peak in the fallout doses. This possibility has been investigated[28]. Wakeford *et al.* analysed data from eleven cancer registries with childhood leukaemia incidence data (four of the registries had data from the early 1950s). There was no peak in childhood leukaemia risk following the peak in fallout doses.

A particular suggestion has been made that tritium is far more dangerous than is generally imagined and that this component of nuclear discharges might be responsible for clusters[29]. It is true that evidence suggests that tritium emissions are more effective than some other low LET radiation at inducing cancers[30] by a factor of about two. However, as with fallout nuclides generally, the tritium emissions from the intensive nuclear testing of the late 1950s and early 1960s failed to produce any excess of leukaemias[31] which argues strongly against the idea that tritium might be especially dangerous. Equally, a comparison[32] of two installations which release tritium, Kruemmel in Germany and Savannah River in the United States, showed that the former released relatively little tritium but that leukaemia rates in the vicinity were significantly elevated, while tritium releases from the latter were several orders of magnitude higher though leukaemia rates in the vicinity were non-significantly less than expected.

What have we learned about clusters of childhood cancer around nuclear installations?
There is no doubt that there were some such clusters, notably in the vicinity of the Sellafield reprocessing plant. The clusters have been extensively studied. Dose assessments indicate that the clusters do not appear to be due to planned or accidental releases of radioactivity from the plant. Nor does it seem plausible that they are due to occupational exposures of the parents of the children.

Another possibility has been suggested, a viral mechanism. Such suggestions have been made by Greaves and by Kinlen. Greaves suggested that delayed exposure to infection in infants aged less than one year impaired the development of the immune system and left the child at increased risk of developing Acute Lymphoblastic Leukaemia[33, 34]. Kinlen has proposed a Population Mixing hypothesis under which

- some childhood leukaemia is a rare response to an as yet unidentified infection;
- individuals in isolated or rural areas would be less likely to have been exposed to this agent in early life and would be susceptible to infection by it later[35, 36];
- marked influxes of people into rural areas would lead to mini-epidemics of subclinical infections by this agent; such infections are mainly immunizing but in rare cases lead to childhood leukaemia.

Kinlen conducted a meta-analysis of 17 studies of rural Population Mixing[36]. The results are summarised in Table 4. Kinlen argues that the finding of an elevated relative risk below age 2 years at a level similar to that for 0−4y and 0−14y, counts against the Greaves Hypothesis. We also note that Kinlen has been critical of COMARE's discussion of Population Mixing [37, 38]. He also points out that continuation of the Sellafield cluster into the 1980s can be explained under the population mixing hypothesis as a consequence of population mixing during the construction of THORP (the THermal Oxide Reprocessing Plant).

Writing in 1989, Doll suggested 'pre-emptive infection' as a mechanism to explain increasing time trends in recorded childhood acute lymphoblastic leukaemia incidence, and relatively low rates in children from more deprived communities[39]. This idea was originally proposed by Stewart[40, 41] and developed by Greaves[42]. Acute leukaemia in children pre-disposes to fatal infection, and does not always have obvious clinical symptoms. Some children might die of infection caused by underlying leukaemia without leukaemia ever being diagnosed. In Britain, this might have been more frequent in the 1970s and 80s (when childhood infection mortality was much higher and paediatric oncology was less well developed) and in more deprived communities (where primary health care tends to be less good, and childhood infection mortality is higher). Clinical evidence from the 1980s and 90s supports this suggestion in the context of the socioeconomic gradient[43]. Time trends suggest that (relative to the early 2000s) childhood leukaemia might have been under-diagnosed by 20% in the 1970s and 80s. Greater awareness of the possibility of cancer around nuclear installations might have resulted in a smaller chance of leukaemias being missed than in other areas. This might explain an apparent relative risk of 1.25 in these areas, which could be considered at least a partial explanation for clusters in these areas at that time. Under-diagnosis is likely to have been greater in the 1960s. However, it is highly implausible that greater awareness could result in a local ten-fold increase in diagnosis of leukaemia over the period 1963−1990, as would be required to explain the Sellafield cluster fully.

## 6. Summary

For most people natural radiation exposures exceed those from artificial sources. Exceptions are nearly all due to medical irradiation.

There is no doubt that radiation, even low level natural radiation, causes cancer.

Clusters of childhood cancer have occurred around some nuclear installations (notably Sellafield). But it seems very unlikely that radiation from the discharges in normal operations of nuclear installations is the cause. Nor is it plausible that the Sellafield cluster is a consequence of accidental releases from the plant.

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## Disclosure

The authors declare that they have no conflict of interest.

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