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Review paper

Risk of low-dose radiation and the BEIR VII report: A critical review of what it does and doesn't say

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ABSTRACT

This article briefly reviews the history behind the BEIR VII report and the use of the linear no-threshold hypothesis. The BEIR VII committee considered four primary sources of data on the stochastic effects of ionizing radiation. These were environmental studies, occupational studies, medical studies and studies on the atomic bomb survivors. These sources are briefly reviewed along with key studies that run counter to the LNT hypothesis. We review many of the assumptions, hypotheses and subjective decisions used to generate risk estimates in the BEIR VII report. Position statement by the Health Physics Society, American Association of Physicists in Medicine, and UNSCEAR support the conclusion that the risk estimates in the BEIR VII report should not be used for estimating cancer risks from low doses of ionizing radiation.

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1. Introduction

The topic of radiation associated risks is one that has come to prominence over the last 10 years with the significant increase in the use of ionizing radiation in medical imaging. This topic, coupled with well-publicized events such as the Fukushima nuclear accident has heightened public awareness of this issue. People fear what they do not understand and radiation risk is a textbook example of a topic that is poorly understood and feared by both patients and physicians [1]. In an Op-Ed article in the New York Times (Oct 21, 2013) entitled "Fear vs. radiation: the mismatch", David Ropiek discussed our fear of radiation which stems from our understandable fear of the power of nuclear weapons and went on to state that "*... in the 70 years since Hiroshima and Nagasaki, epidemiological and scientific studies have shown that at radiation doses of less than 100 mSv, radiation causes no detectable elevations*

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in normal rates of illness and disease. Yet our response to radiation continues to contradict the robust evidence that ionizing radiation is a relatively low health risk".

The increased exposure of patients to medical radiation has caused some authors to predict thousands of radiation-induced cancers in the US population in the coming years. One study predicted an annual toll of 14,500 cancer deaths from CT examinations [2], and Brenner and Hall [3] estimated that CT scans will be responsible for 1–2% of all future cancers in the U.S. These predictions and several others like them [4,5] stem from risk estimates derived from reports by the committee to assess health risks from exposure to low levels of ionizing radiation. This committee is under the auspices of the National Academy of Sciences. The most recent report [6] is known as the Biological effects of Ionizing Radiation (BEIR) VII Phase 2 and was issued in 2006. A National Academy of Sciences press report at the time [7] quoted the chair of the committee, Richard R. Monson, as stating "*The scientific research base shows that there is no threshold of exposure below which low levels of ionizing radiation can be demonstrated to be harmless or beneficial* ". The press report went on to state that "*Living at low altitudes, where there is less cosmic radiation, and living and working on the upper floors of buildings, where there is less radon gas — a primary source of natural ionizing radiation — are factors that could decrease exposure*". Given the prominence that this report has in our understanding of the risks associated with low doses of ionizing radiation, and the inherent warnings in the accompanying press release, it is important to be aware of the limitations in the data used to generate its risk models, and the assumptions inherent in these risk models.

2. Historical perspective

The BEIR VII report is the latest in a series of reports that span over 60 years, starting with the BEAR committee in the 1950 s. A key component of the risk models developed by the BEIR VII committee is the use of the linear no-threshold (LNT) hypothesis. This model was originally proposed in 1928 [8] to account for genetic changes in the genome from background ionizing radiation, thereby offering an explanation of Darwin's theory of evolution. While this theory was shown to be incorrect with respect to the mutagenic effects of radiation, the LNT model became adopted by the radiation genetics community in an attempt to predict the carcinogenic effects of ionizing radiation [9,10], and eventually was adopted by the first committee on the biological effects of atomic radiation (BEAR) [11]. In the late 1960s, this committee was renamed the BEIR (Biological Effects of Ionizing Radiation) committee.

Given the prestige of the National Academy of Sciences, the recommendation by the BEIR committee to use the LNT model has been widely adopted both in the US and elsewhere. This has occurred despite numerous scientific studies and review articles that highlight the inadequacy of the LNT hypothesis to explain the carcinogenic effects of low doses of ionizing radiation [12–16].

3. BEIR VII – sources of data on stochastic effects of ionizing radiation

The BEIR VII committee considered four primary sources of data on the stochastic effects of ionizing radiation. These were environmental studies, occupational studies, medical studies and studies on the atomic bomb survivors. Below we have briefly reviewed some of the key studies in each of these areas.

3.1. Environmental studies

The BEIR committee reviewed studies from 1990 through 2004 and concluded that most were ecologic in design and therefore of limited value in estimating the cancer risk from ionizing radiation. These included studies of populations living near nuclear facilities, populations exposed to atmospheric testing or other environmental release of radiation, populations exposed from Chernobyl and populations exposed to high natural background radiation. The studies of greatest interest are those relating to Chernobyl. While there was strong evidence of increase in thyroid cancer due to the high doses of I-131 released, the BEIR VII report concluded that "*there is no evidence of an increase in any solid cancer type to date*" (BEIR VII, page 228).

The committee reviewed 4 studies of populations living in areas of high natural background radiation in China and India. No increase in disease rate was observed in any of these studies. One study not included in their review was that of Tao et al. [17]. They performed a 26-year study of over 125,000 subjects living in an area of high natural background radiation in Yangjiang, China. Risk estimates were negative (i.e. radioprotective effect), although this did not reach statistical significance.

Because these studies were descriptive in nature and ecologic in design, they were considered of limited use by the BEIR VII committee, and largely dismissed from further consideration. This is unfortunate as the absence of an effect in so many studies is itself an indication that the effects of radiation may not follow the LNT model of radiation risk.

One topic not included in the review of environmental studies by the BEIR VII committee was radon exposure. This was reviewed in an earlier BEIR VI report [18] which had concluded that ~19,000 excessive lung cancer deaths occur annually in the U.S. due to residential radon exposure. This was based on data from miners who are exposed to radon levels orders of magnitude higher than those found in residential homes. A more recent prospective study of ~1.2 M participants showed positive associations between ecological indicators of residential radon and lung cancer [19]. Participants with mean radon concentrations above the EPA guideline value (148 Bq/m^3) experienced a 34% (95% CI, 7–68) increase in risk for lung cancer mortality relative to those below the guideline value. The authors concluded that their study supported "*further efforts to reduce radon concentrations in homes to the lowest possible level*" [19]. In one of the most rigorous case-control studies of lung cancer incidence vs. residential radon exposure, Thompson et al. [20] found that the odds of lung cancer did increase for radon levels above the EPA guideline value, in agreement with the study of Turner [19]. However, at radon levels below the EPA guideline value, they found a statistically significant hormetic effect of radon on lung cancer (Fig. 1). This finding runs contrary to the recommendation from Turner et al., and from the National Academy of Sciences press release for the BEIR VII mentioned above.

3.2. Occupational radiation studies

Occupationally exposed workers in the nuclear power industry are in theory an ideal group in which to study the effects of low levels of ionizing radiation. The BEIR VII committee reported that "*in most of the nuclear industry workers studies, rates for all causes and all cancer mortality in the workers were substantially lower than the reference population*" (BEIR VII, page 194). The BEIR VII committee concluded that "*possible explanations include the healthy worker effect and unknown differences between the nuclear industry workers and the general population*" (BEIR VII, page 194). As a result, the BEIR VII committee eliminated them from further consideration. One of the most intriguing studies that was not reviewed by the BEIR VII committee was that of Sponsler and Cameron [21]. They

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