What is the Dose-Response Relationship between Vitamin D and Cancer Risk?

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An inverse association between serum 25-hydroxyvitamin D [25(OH)D], and risk of cancers of the colon, breast, and ovary has been reported in well-conducted observational studies.1 These studies have been supported by numerous natural experiments, specifically, studies that examine differences in incidence rates according to naturally occurring variations among populations in their ambient exposure to solar ultraviolet B irradiance, the main source of vitamin D.2-6 The presence of a dose-response gradient is one of the key criteria for determining whether an association is causal. This review describes the dose-response gradient between serum 25(OH)D and risk of these cancers. It also projects dose-response gradients for cancers of several other sites and suggests a possible mechanism for the dose-response gradient of vitamin D in cancer.

Combining data from observational studies revealed an inverse association of serum 25(OH)D with risk of colon7 and breast cancer8 (Figures 1 and 2). A dose-response gradient for ovarian cancer and 25(OH)D concentrations was obtained from a recent cohort study.9 The gradients were confirmed by an analysis of modeled and reported winter serum 25(OH)D levels and estimated age-standardized incidence rate estimates for 177 countries for 2002 from the International Agency for Research on Cancer (IARC) GLOBOCAN database. Serum 25(OH)D levels in each country were obtained from previous studies or modeled based on winter solar ultraviolet B irradiance by country, adjusted for winter cloud cover data obtained from the NASA international satellite climatology project (ISCCP).

An inverse, monotonic dose-response gradient between serum 25(OH)D and risk of cancers of the colon and breast beginning at levels from 24 to 32 ng/mL was observed. The asymptotic (flat) portion on the left side of the dose-response curve was shortest for colon cancer (from 0 through 12 ng/mL) and longest for breast and ovarian cancer (from 0 through 25 ng/mL) and most other vitamin D-sensitive cancers. Based on observational studies, the first visible increment in prevention of colorectal cancer occurs with serum 25(OH)D levels ≥ 22 ng/mL, while the first visible increment in prevention of breast cancer occurs with serum 25(OH)D levels ≥ 32 ng/mL. Serum 25(OH)D variation below these levels generally would have little or no influence on cancer risk.

The lower limit for any benefit of vitamin D would correspond to 1000 IU/d of vitamin D3 for the first meaningful increment of colorectal cancer prevention and 2000 IU/d for the first meaningful increment of breast cancer prevention. We estimated that 50% of colon cancer incidence in North America could be prevented by lifelong maintenance of serum 25(OH)D level ≥ 34 ng/mL (Figure 1). This did not require extrapolation beyond known data points. Prevention of 30% of breast cancer incidence in North America would be expected with lifelong maintenance of a substantially higher serum 25(OH)D level of ≥ 42 ng/mL (Figure 2). Based on a prediction involving linear extrapolation, a projected 50% reduction of breast cancer incidence could potentially be achieved by lifelong maintenance of serum 25(OH)D level ≥ 52 ng/mL.

The dose-response gradients described here provide a quantitative basis for formulating recommendations to the medical community and general public for primary prevention of colorectal and breast cancer, and should be used for that purpose. In North America, a projected 50% reduction in colon cancer incidence would require universal intake of 2000 IU/d of vitamin D3, while a similar reduction in breast cancer incidence would require 3500
IU/d. The intake expected to prevent half of breast cancer incidence would be above the 2000 IU/d upper limit established by the National Academy of Sciences.¹⁰ These gradients for cancer risk suggest that the upper limit should be revised upward, since there is considerable benefit, and no established adverse effect of vitamin D₃ intake below 10,000 IU/d.¹¹,¹² In the meantime, 2000 IU/d of vitamin D₃ for all individuals aged 12 years and older would be far safer than the present median adult intake in the US of approximately 230 IU/d.¹⁰ Use of ergocalciferol (vitamin D₂), which is popular in Europe and is used in some major US brands of multivitamins, should be discontinued immediately in favor of vitamin D₃.¹³-¹⁵

Vitamin D status can be enhanced with very brief...
The mechanism of vitamin D in cancer is most easily explained by the recognition that malignancies are characterized by a continuum of progressive evolutionary changes from the normal to the malignant cell. The role of vitamin D in genesis of cancer is most easily understood in terms of its pivotal role in an evolutionary process that begins at the level of decoupled epithelial cells. Cells that are coupled to their neighbors cannot compete with one another for resources because they are limited in migration by neighboring cells. When the cells decouple, population dynamics become operative. Through natural selection, cells that have acquired somatic mutations that confer a reproductive advantage will eventually become predominant in their tissue compartment.

The intestinal epithelial cells in high-risk individuals reproduce much (about 4 times) faster than those in other people. Unfortunately, rapid reproduction comes at a cost, generally loss of fidelity of reproduction of the DNA. This occurs when there is not enough time between cell cycles for repair of the nearly inevitable loss of structural integrity of DNA that occurs during replication.

An example of a first step toward cancer due to vitamin D deficiency may be loss of a protein coded by a growth suppressor gene, such as the p53 tumor suppressor protein. The function of this gene can be reduced or lost due to harm to the gene, or to weak activation of the gene. Since the p53 gene is up-regulated by vitamin D metabolites, the production of p53 protein is reduced when these metabolites are insufficient. This can occur in response to dietary or environmental factors, such as vitamin D deficiency. Since p53 inhibits replication, its loss or reduction cuts the doubling time of the cell, causing the cell’s progeny to advance through generations faster. This confers a selective reproductive advantage on the progeny.

If a decoupled epithelial cell acquires a 1% selective advantage over neighboring cells in reproduction, its progeny will eventually consist of a clone occupying 99% of the tissue compartment in which the malignancy arose. This requires 9000 generations, equivalent to approximately 25 years, if the reproductive rate is one generation per day, as it is for colonocytes in cancer-prone individuals. Consistent with this evolutionary sequence, the median induction period for colonic (and most solid tumors) is 20 to 25 years. If the cellular reproductive rate is normal, the same 9000 generations would grow a malignant clone of similar mass, but it would take 99 years. At that late point in the life cycle of the individual, it is likely that another disease would have claimed the person’s life. Concern about such a slow-growing malignancy would be irrelevant.

The mechanism of the dose-response relationship between vitamin D and cancer risk is that vitamin D and
its metabolites exert substantial control on the rate of evolution of cancer in epithelial tissues. When an individual’s vitamin D status is very high, the reproductive rate of epithelial cells will be the minimum needed to maintain health. The epithelial cells are reliably self-adherent and undergo a normal life cycle. When vitamin D status is low, the reproductive rate of epithelial cells increases abnormally, leading to loss of fidelity in DNA replication and acquisition of somatic mutations. If the early genetic victims of replication defects include tumor suppressor genes such as p53, the evolutionary process is further accelerated. Vitamin D is pleiotropic and also prevents cancer by several other mechanisms, including maintenance of normal differentiation, enhancement of proliferation and metastasis of the malignancy may be possible and should be attempted.

The microevolutionary progression of cancer is best avoided. It is wiser to prevent cancer from its earliest stage by maintaining vitamin D adequacy (serum 25(OH)D \( \geq 55 \) ng/mL). Before a massive degree of microevolution of the cancer has occurred, and when tumor-suppressor genes that respond to the vitamin D receptor-ligand complex are still present, arrest of proliferation and metastasis of the malignancy may be possible and should be attempted.

Maintaining and restoring vitamin D adequacy has the potential to play a unique role in primary prevention and as an adjunct to existing treatments for cancer. An approach to using vitamin D to prevent cancer may be to maintain a serum 25(OH)D level of \( \geq 55 \) ng/mL throughout life. It would also be wise to promptly restore the usually deficient serum 25(OH)D level of all individuals with newly diagnosed invasive cancers of the colon, breast, and ovary to \( \geq 55 \) ng/mL unless hypercalcemia is present.

It has been shown that the necessary 55 ng/mL concentration of 25(OH)D can be easily maintained, as it is in healthy lifeguards. Any physiological state that predisposes to cancer is unsafe, including a low serum level of 25(OH)D. Monitoring tools are now available that support maintaining the 25(OH)D level in a range that is high enough for safety but low enough to avoid major risks.

Based on the dose-response curves identified in this report and modeled national baseline median population winter 25(OH)D levels, the projected number of cases that could be prevented in North America with universal attainment of a serum 25(OH)D level of \( \geq 55 \) ng/mL would be at least 60,000 cases per year of colorectal cancer and 85,000 cases per year of breast cancer. The projected number of cases that could be prevented annually in the world with this serum level of 25(OH)D would be approximately 250,000 cases of colorectal cancer and 350,000 cases of breast cancer.

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REFERENCES

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