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Big Punched Come in Nanosizes for Chemoprevention

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Abstract

Literature to support the chemopreventive potential of several bioactive molecules has been prolific and convincing, but the clinical development of these agents has been slow. Major hurdles for development of bioactive chemoprevention approaches include low potency, lack of reliable formulations with high bioavailability that are suitable for oral administration, and relevant preclinical primary prevention models that use meaningful doses that can be translated to humans. The paper presented in this issue (Grandhi and colleagues) is an important step forward in this direction. It shows the efficacy of an oral, low dose, solid-lipid nanoparticles encapsulated curcumin and aspirin combined with free sulforaphane for long-term chemoprevention of pancreatic cancer in a carcinogen-induced hamster model. Reproducing this benefit in multiple cancer models, accompanied by development of intermediate markers of response will allow rapid translation of these findings. It will constitute the first successful multipronged attack at key pathways known to initiate and promote carcinogenesis. Cancer Prev Res; 6(10); 1–4. ©2013 AACR.
bioavailability and the need to consume mega-doses (up to 8 g) has severely limited the rapid clinical development of curcumin.

Various labs using in vivo models, including 9,10-dimethyl-1,2-benzanthracene–induced mammary cancer in rats (15), azoxymethane-induced colonic aberrant crypt foci in rats (16), and benzo[a]pyrene-induced forestomach cancer in mice (17) have shown that SFN prevents carcinogen-induced cancer in rodents. Oral administration of SFN inhibits malignant progression of lung adenomas induced by tobacco carcinogens in A/J mice (18). SFN suppresses cancer cell proliferation, elicits G2-M phase cell-cycle arrest, and induces apoptosis. The molecular mechanisms underlying its effects include inhibition of signal transducer and activator of transcription (Stat3), NF-kB, Akt, mitogen-activated protein kinase, p53, COX-2, NF-E2-related factor-2 (19). Pharmacokinetic studies have shown that dietary-absorbed SFN has wide distribution in the body, reaches target tissues in its active form, and attains μmol/l levels in the blood (20, 21). In a study led by Visvanathan at Johns Hopkins, an oral dose of broccoli sprout preparation (containing 200 μmol SFN) formulated as a fruit drink consumed by women 1 hour before the reduction mamoplasty resulted in a mean accumulation of SFN metabolites of 1.45 ± 1.12 pmol/mg breast tissue from the right breast and 2.00 ± 1.95 pmol/mg from the left breast (21). In its bioavailability and effects in preclinical models, SFN definitely shows promise for further development as a chemopreventive agent.

More than other chemopreventive agents, nonsteroidal anti-inflammatory drugs (NSAID), such as aspirin, have garnered the attention of a large number of epidemiologists and clinicians. Studies investigating the association between long-term use of aspirin and cancer risk and mortality have shown that daily intake of aspirin for 5 years or longer reduces mortality from several cancers (22). Metanalysis of randomized studies showed positive effects of both low dose (75–300 mg daily) and high-dose (≥500 mg daily) aspirin intake (22). At low-doses, aspirin acts mainly by an irreversible inactivation of platelet COX-1 activity, thus affecting thromboxane A2-dependent platelet activation. However, COX-independent mechanisms for the anticancer effects of aspirin have also been shown, including suppression of Wnt/catenin pathway, Raf/Ras/ERK pathway, and NF-kB that lead to an inhibition of cell proliferation and induction of apoptotic stimuli (23, 24), suggesting a role in chemoprevention.

Because chemopreventive agents are expected to be taken for a long time, there is an increased interest in developing “combination chemopreventive strategies” using low doses of chemopreventive and pharmacologic agents with different mechanisms of action to simultaneously target multiple pathways. In addition to increasing efficacy and limiting toxicity, these combination strategies could limit the development of therapeutic resistance often associated with drugs that target single molecules. In this issue of the journal, Prabhu and colleagues report dramatic effects of a combinatorial nanotechnology-based oral chemoprevention regimen in a preclinical N-nitrosobis (2-oxopropyl) amine (BOP)-treated-Syrian golden hamster model in suppressing the progression of pancreatic intraepithelial neoplasms (PanINs) to pancreatic cancer (25). This study has several strengths: (i) a novel chemopreventive regimen that combines the triple punch of aspirin, curcumin, and SFN (ACS); (ii) solid-lipid nanoparticles (SLN) encapsulation to improve efficacy of the ACS combination; (iii) oral administration; and (iv) the low doses needed for optimal effects. The nanoencapsulated AC and free SFN were able to reduce tumor burden more effectively than the free forms of the drugs. Oral administration of nanoencapsulated ACS regimens reduced tumor incidence by 75% at doses that were 10 times lower than the free drug combinations. The fact that all 3 drugs in the ACS combination have different mechanisms of action ensures not only higher efficacy via simultaneous targeting of multiple pathways but also, potentially, minimizes chances of developing resistance.

Although preclinical studies over the last few decades have shown convincing evidence to support the chemopreventive potential of several bioactive molecules, the clinical development of these agents has been disappointing. Major hurdles for development of bioactive chemoprevention approaches include low potency, lack of suitable formulations for oral administration, low bioavailability, and limited availability of suitable preclinical primary prevention models for the different cancer types and subtypes. Primary prevention clinical trials require a large number of subjects, many decades of follow-up due to long latency of most cancers, and incur heavy costs. To ensure their success, it is important to establish a constant supply of bioactive compounds and standardize methods for production, storage, and formulation to guarantee delivery of a given concentration of bioactive component. Another pitfall is that preclinical studies often use higher doses of bioactive reagents for shorter duration to show the efficacy of a bioactive compound. It is very important to use meaningful doses in preclinical studies that can be achieved in the clinical setting and can be safely administered for longer duration. This study led by Prabhu takes an important first step forward and shows the efficacy of an oral, low dose, nanotechnology-based combination treatment regimen for long-term chemoprevention.

So what is the innovation that rendered the ACS combination of chemopreventive compounds so potent? In recent years, nanotechnology has been used to solve several limitations associated with bioactive compounds. Most bioactive compounds are to a certain degree lipophilic, a property which is oftentimes required and appreciated because of the phospholipidic nature of cell membranes, thus aiding absorption through the intestinal wall following oral administration and subsequent pharmacologic action in the target tissue. High lipophilicity, on the other hand, improves permeability of the compound but on the other hand translates into poor aqueous solubility. Poor aqueous solubility is the major hurdle in development of orally delivered bioactive compounds, because the first step in the oral absorption is the dissolution of the compound in
Nanoparticles have shown great potential for improving the bioavailability of bioactive compounds and were first developed to deliver low water-soluble cancer medications in solid or liquid formulations. These have been formulated with biodegradable and biocompatible polymers such as polyactic acid, starch, chitosan, and so on. The term “nanochemoprevention” was coined by Mukhtar and colleagues who showed the superior performance of ECGC in a pegylated polyactic acid polymer in a prostate cancer xenograft model (26). Curcumin has been incorporated into nanoparticles for therapeutic and preventive effects for example, into polymeric amphiphile, mPEG-Polyglycol (27), or a water-soluble polyethylene glycol (PEG) conjugate (28), which have shown cancer-cell proliferation inhibitory effects at much lower concentrations than free curcumin. In our center, polymer nanoparticles composed of N-isopropylacrylamide, vinylpyrrolidone, and acrylic acid were used to encapsulate curcumin by Maitra and colleagues, who showed that these particles could be administered intraduurally at 20-fold lower doses than oral curcumin to attain comparable chemopreventive effects in a carcinogen-induced mammary tumor model (29). In an earlier publication in this journal, Prabhu and colleagues showed the efficacy of an oral regimen of poly(lactide-co-glycolide biodegradable copolymer nanoparticles encapsulating aspirin and folic acid with free calcium to significantly decrease aberrant crypt formation in a colon tumor model (30). Among the agents used to make nanoparticles, lipids have emerged as an attractive candidate because of their ability to enhance the bioavailability of compounds with poor aqueous solubility.

Solid lipid is one of the physical forms of lipid that is used to formulate nanoparticles known as SLNs. SLNs are colloidal carriers that remain solid at room temperature and body temperature and are a great alternative to emulsions, liposomes, and polymeric micro- and nanoparticles. SLNs offer multiple advantages such as small size (50–500 nm), possibility of large-scale production, smooth and spherical shape, and lower toxicity than polymeric nanoparticle (5). SLNs are especially suitable for the development of formulation for lipophilic and, in general, poor water-soluble drugs made from either natural or artificial solid lipids (31, 32). Some of the concerns associated with SLNs are low payload for a number of drugs, complexity of the physical state of the lipid, and high water content which during storage and administration compromises stability. Stability, in fact, is the major issue with SLNs that needs to be standardized, because physicochemical stability of SLNs is a fine balance between long-term storage stability and its destabilization that is necessary for release of the bioactive compound in its biological environment (33). Despite its few shortcomings, SLNs have the potential to improve the pharmaceutical properties of bioactive compounds and aid their clinical development, opening up new avenues for research in chemoprevention.

Because multistep development of human cancer includes sustained proliferative signaling, evasion of growth suppressors, resistance to cell death, induction of angiogenesis, and activation of invasion and metastasis, an ideal chemoprevention strategy would be to develop a multi-pronged approach to simultaneously target and tame these processes. Bioactive compounds often lack a specific target and instead modulate multiple oncogenic pathways in a multitude of cancer types. Far from being a drawback, we believe that this intrinsic property can potentially enable them to target multiple oncogenic pathways concurrently impacting various stages of cancer progression. Bioactive compounds do have inherent problems related to aqueous solubility and bioavailability, but as illustrated by this very promising study of Grandhi and colleagues, optimization of dose, route, and innovation using nanotechnology-based approaches will be the key to advance the chemoprevention field in the near future where small, sustainable doses of novel combination-cocktails will redefine the coveted “silver bullet” for chemoprevention.

Rapid extension of this work to test efficacy in vivo in model systems of multiple cancer types made possible by ready availability of uniform, quality controlled preparations of ACS, combined with the development of intermediate markers of response in serum and target tissue will establish the facile translational of these findings to the clinic.

Disclosure of Potential Conflicts of Interest
S. Sukumar is a consultant/advisory board member of CBCRP. No potential conflict of interest was disclosed by the other author.

Authors’ Contribution
Writing, review, and/or revision of the manuscript: D. Sharma, S. Sukumar

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