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Senolytic and senomorphic drugs: The future value, importance of nano drug delivery systems and quantum dots

Editorial Article

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Changes in the scientific and technological fields do increase average lifespan; as a result, the world's population is gradually aging. This perspective will bring anti-aging drugs, better formulation alternatives, and delivery systems into sharper focus in the near future. As pharmacists and scientists, we must give this issue the necessary attention in a timely manner and conduct our studies. Cellular aging is defined by the cessation of permanent cell growth while remaining metabolically active and releasing pro-inflammatory, tissue-damaging, and reprogramming signals into the environment. This secretory profile, called the 'senescence-associated secretory phenotype' (SASP), plays an important role in the biological basis of many age-related diseases. Recently developed seno-therapeutic approaches aim to either selectively eliminate these cells or suppress harmful secretion patterns.

Senolytic drugs aim to selectively kill aged cells by targeting pathways that provide resistance to apoptosis. Senomorphic drugs, on the other hand, reduce SASP production and tissue damage without eliminating the cells; therefore, they are more important for the long-term management of chronic inflammation, tissue deterioration, and loss of function. These two approaches are not mutually exclusive in transforming the biology of aging into treatment; rather, they are often seen as complementary strategies.

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Biological foundations and examples of senolytic drugs

The basic principle of senolytics is to suppress 'senescent cell anti-apoptotic pathways' (SCAPs) or similar anti-apoptotic networks that aged cells depend on to survive. In these cells, the BCL-2 family, PI3K, the p53/p21 axis, HSP90, and various tyrosine kinase-related pathways can be irregularly activated; therefore, more targeted strategies have been developed than traditional cytotoxic approaches.

Senolytics that stand out in the clinical and preclinical literature include dasatinib, quercetin, fisetin, navitoclax, and some HSP90 inhibitors. The combination of dasatinib and quercetin has shown potential to reduce the burden of aged cells and certain aging markers in early-phase human studies and various animal models; however, navitoclax, despite a strong biological rationale, requires careful evaluation due to toxicities such as thrombocytopenia. This situation indicates that although senolytics have a strong conceptual framework, issues related to safety and cell selectivity remain fundamental challenges that need to be addressed.

The role of senomorphics

Senomorphic drugs aim to reshape the harmful biological output of aging cells rather than destroying all of them. By specifically targeting mTOR, NF-κB, JAK/STAT, p38MAPK, and related inflammatory nodes to reduce SASP production, this class of drugs is attractive for more controlled management of chronic diseases.

Metformin and rapamycin/rapalogs are among the most discussed examples in this class. It has been reported that metformin can suppress NF-kB-related pro-inflammatory transcription, while rapamycin can reduce the translation of SASP components via mTOR. Therefore, senomorphics have the potential to limit tissue damage without completely eliminating certain aged cell populations that may be physiologically beneficial; this aspect offers strategic value, especially in cases requiring long-term use.

Future value and translational potential

The future value of senolytic and senomorphics drugs is not solely limited to an 'anti-aging' discourse; their true significance lies in their capacity to target common biological nodes that fuel multimorbidity. Studies indicate that cellular aging is implicated in many areas, including cardiovascular diseases, osteoarthritis, fibrosis, metabolic disorders, neurodegenerative processes, and tissue deterioration after cancer treatment; therefore, successful senotherapeutics

may affect clusters of age-related pathologies rather than a single disease.

However, the future of the field depends on several conditions. First, reliable biomarkers need to be developed to indicate which patient groups will benefit from which senescence subtype. Second, it is essential to distinguish between physiologically and pathologically aged cells; because indiscriminate removal of all senescent cells could negatively impact beneficial processes such as tissue repair and embryonic development. Third, new clinical designs such as intermittent dosing, tissue-specific targeting, and combination therapies will determine the risk-benefit balance of these drugs.

The importance of nano drug delivery systems

Nano drug delivery systems are probably the most critical technological step in translating senotherapies into clinical value. This is because the biggest issues with current senolytics are systemic toxicity, low target specificity, short half-life, limited bioavailability, and unwanted tissue exposure; nanosystems can reduce these problems by redesigning solubility, release kinetics, tissue distribution, and pharmacokinetic behavior.

In the literature, liposomes, polymeric nanoparticles, mesoporous silica nanoparticles, calcium carbonate nanoparticles, nanoemulsions, dendrimers, and exosome-based carriers stand out. These systems can enable more selective drug release via surface markers such as high SA-β-gal activity in aged cells or tissue-specific micro-signals such as CD9, B2M, CD36, and CD47. In particular, nanoparticles coated with galactose or oligosaccharides, which utilize increased lysosomal β-galactosidase activity in senescent cells to preferentially release the drug, are considered strong examples of the 'second-generation senolytic' approach.

The value of nanocarriers is not only in treatment but also in diagnosis and treatment monitoring. Some platforms provide a theragnostic approach by combining imaging agents and therapeutic payloads in a single system; thus, it is possible to simultaneously monitor which tissues contain how many aged cells and how the treatment response changes. This approach is very important for translating aging biology into personalized medicine.

The special significance of quantum dots

Quantum dots are semiconductor nanocrystals on the scale of a few nanometers, and they hold a special place in biomedical nanotechnology due to their size-dependent optical properties, tunable emission spectra, high surface areas, and functionalizable structures. Studies emphasize that

quantum dots offer a distinct 'traceable carrier' advantage over traditional nanocarriers because of their capacity for drug conjugation, targeted delivery, real-time imaging, and controlled release monitoring.

This feature is especially important in the field of senotherapy. Not only does it involve the delivery of senolytic or senomorphic molecules specifically to the target tissue, but also tracking where they go in the body, whether they enter cells, and when they are released, which significantly enhances the assessment of efficacy and safety. Quantum dots, thanks to their fluorescent signal-generating properties, can combine drug delivery and bioimaging probe functions on the same platform; this makes them strong candidates for theranostic systems.

Additionally, the high surface area of quantum dots allows for the loading of multiple drugs, ligands, or nucleic acids. This could enable, in the future, the integration of, for example, a senolytic agent, an imaging label, and a cell-specific targeting ligand into the same nanoplatform. Such a structure could support multimodal and precise interventions in tissues where aging cells are heterogeneous.

However, the most significant issues preventing the clinical use of quantum dots are toxicity and biocompatibility. In particular, some quantum dot formulations containing heavy metals raise concerns about long-term tissue accumulation, oxidative stress, and safety; therefore, surface modification, biodegradable coatings, and the development of safer core materials are essential. Despite this, quantum dots are considered a strategic technology for future precision and personalized theragnostics because they can combine imaging and delivery in a single system.

In conclusion, senolytic and senomorphic drugs are among the most important pharmacological advances demonstrating that aging is not just a passage of time but an alterable biological process. Senolytics have the potential to reduce age-related disease burden by eliminating aged cells, while senomorphics work by suppressing the harmful secretory effects of these cells. However, the true clinical value of this potential depends on the discovery of accurate biomarkers, safe patient selection, and the development of nanocarrier platforms that enhance targeted delivery.

In this context, nanodrug delivery systems appear to be key to overcoming the main challenges of targeted therapies: specificity and toxicity. Quantum dots are among the most notable components in this field because they can serve as both carriers and imaging agents. Developing safe and biocompatible

quantum dot-based systems could be a transformative step, advancing targeted therapy from experimental biology to precision medicine.