International Journal of Public Health and Medical Research
ISSN: 3006-7707 (Print), ISSN: 3006-3752 (Online)
Volume 6, Number 7, Year 2026
DOI: https://doi.org/10.62051/ijphmr.v6n7.09

Exploration on the Influence of Oxidative Stress on the Progression of Age-related Degenerative Lesions

Yiwen Wang

School of Basic Medical Sciences, Henan University, Kaifeng, China

ABSTRACT

Research on how oxidative stress affects the development of age-related degenerative diseases. Rather than considering oxidative stress as an increase in free radicals, this paper now refers to it as a fluctuating disorder in redox homeostasis that involves reactive oxygen species, antioxidant defence, mitochondrial function, inflammatory amplification and damaged cell repair. Based on the classic theories of ageing and later review literature, this paper examines how oxidative stress contributes to the accumulation of molecular damage and promotes structural and functional deterioration in ageing tissues. Oxidative stress is also related to disease, and at the same time, it is a type of damage that occurs in blood vessels, nerves and metabolism. Therefore, it has been proposed that the development of degenerative changes in old age is the result of multiple interconnected redox, inflammatory and signalling pathways rather than single-cause damage to tissues.

KEYWORDS

Oxidative stress; Aging; Degenerative lesions; Reactive oxygen species; Redox homeostasis; Age-related disease

1. INTRODUCTION

The oldest people have many degenerative changes in their tissues as a result of ageing. There is a gradual disintegration of the organisation, a loss of cell membrane integrity, and damage to all organs and tissues, such as the nervous system, blood vessels, connective tissue and parenchyma. Although these lesions occur in different places, they often have the same basic reasons. Therefore, research on the degenerative changes in old age should not be confined to individual organs or single lesions.

Oxidative stress is one of the main reasons for the general increase mentioned above. Produce reactive oxygen species (ROS), damage the antioxidant system, injure macromolecules, damage mitochondria, induce inflammation and inhibit repair. However, the idea is often misunderstood to be only about chemical toxicity. Oxidative stress is the loss of redox homeostasis in a living regulatory system.

Oxidative stress and the development of age-related degenerative changes: a review. Oxidative stress is thus considered a dynamic mode of damage to cells that can alter signalling and adaptation over time; at the same time, it is also a cause of delayed tissue injury. Based on the above, this paper will introduce the theoretical basis of oxidative stress, its pathological mechanisms in ageing, its connection to severe age-related diseases, and its diagnostic value in studying lesion changes.

Content from this work may be used under the terms of CC BY-NC 4.0 licence (https://creativecommons.org/licenses/by-nc/4.0/).
Published by Warwick Evans Publishing.

2. THEORETICAL BACKGROUND OF OXIDATIVE STRESS AND AGING

The first idea of free radicals and oxidative stress that has been proposed for a long time is Harman's theory. Harman thinks that ageing and other diseases caused by damage to cells due to free radicals [1]. Although later scholars have expanded on the original formulation, the theory is still necessary because it was the first to connect age-related decline with cumulative molecular damage rather than chronological age.

Later, Harman extended the same theoretical line of research to propose that free-radical reactions are responsible for age-related changes in the body and the development of age-related diseases at all stages of life [2]. The later type is more suitable for addressing oxidative injury as an extended biological problem rather than a single occurrence. Given that these are degenerative lesions, the load may be responsible for explaining the gradual onset of chronic deterioration and the shared molecular features of otherwise unrelated diseases.

A new idea was presented by Finkel and Holbrook; oxidants are not only harmful by-products but also signals in the process of ageing in living organisms [3]. Therefore, the reduction in oxidative stress cannot be classified as toxicity under this system. The degenerative process is also the result of excessive production of reactive species and disruption in the systems that sense, buffer and interpret redox signals.

Finkel extended the above idea to suggest that oxidant signals are also involved in many cellular functions, and oxidative stress may be an indication of dysregulation of the regulatory system rather than only biochemical damage [4]. Cells with continuous redox imbalance may be impaired in proliferation, apoptosis, inflammation and damage repair. Therefore, degeneration occurs due to dysregulated adaptation and direct damage to the tissue.

Betteridge offered a practical and lasting definition of oxidative stress as a disorder in the balance of reactive oxygen species production and antioxidant defence [5]. This definition is still applicable to the study of ageing because it considers context. The same oxidant load can be tolerated by one tissue, but it is harmful to another due to a low antioxidant reserve, high metabolic demand and inefficient repair.

Later studies have included this theory in the wider system of illness. Liguori and his colleagues have shown that oxidative stress is closely associated with ageing and many chronic diseases in older people; therefore, it is now regarded as a type of cross-disease phenomenon rather than a specific biochemical defect [6]. In short, the above theoretical perspectives indicate that oxidative stress is a state of redox imbalance that gradually damages the stability and signalling capacity of tissues.

3. MECHANISMS THROUGH WHICH OXIDATIVE STRESS PROMOTES DEGENERATIVE PROGRESSION

A first mechanism is cumulative macromolecular damage. Valko and others have shown that free radicals and other oxidants damage lipids, proteins and nucleic acids; therefore, normal physiological functions of the body are impaired [7]. Over time, cells will have sustained damage from within and without in the tissue. Therefore, the degenerative lesions that occur are due to an ageing of the cells and an accumulation of oxidative damage, misfolding and fragmentation of essential components.

A second way is the biochemical transmission of injury. Halliwell proposes that oxidative stress is a series of damage caused by a loss of redox balance [8]. Given that oxidative injury can be continuous, it is suitable for treating chronic degeneration. Lipid peroxidation, protein oxidation, damaged membranes and impaired repair pathways may all be present at the same time, making the injured tissue more susceptible to further oxidative damage.

A third way is mitochondrial dysfunction. When the mitochondria do not work normally, more free radicals are generated and energy is lost. Together, these reasons will damage the highly metabolically active parts of the body more easily and cause oxidative stress. Degenerative changes in old age are thus closely related to the combination of redox stress and reduced bioenergetic capacity. Mitophagy deficiency is a fault in the quality control system, not a deficiency of mitochondrial energy production. Aging cells progressively lose the ability to clear damaged mitochondria and regulate mitochondrial turnover. Dysfunctional organelles accumulate and increase electron leakage; as a result, reactive oxygen species (ROS) are generated, and a reduced supply of ATP limits protein repair and other energy-dependent protective measures. Therefore, oxidative injury reduces the efficiency of mitochondria, and damaged mitochondria are unable to regulate redox conditions effectively. Neurons, blood vessels, etc., are long-lived or metabolically active and therefore more easily damaged. Mitochondrial damage may lower the threshold for a functionally significant change in an otherwise compensated lesion in this case. However, the reactive oxygen species in the mitochondria are not uniformly harmful; a low or transient oxidant signal may also be part of adaptation and cellular communication. A pathological problem occurs when the intensity, duration or location of the signal exceeds the capacity of the antioxidant and repair system to restore redox balance [3-7].

The fourth way is disruption of signalling and adaptation. Sustained oxidative stress interferes with the redox-sensitive pathway of stress response, survival, ageing and death, and inflammation. The cell will not only be damaged passively under this circumstance. It may enter a maladaptive state that promotes lesion expansion, failed regeneration or premature functional exhaustion.

The fifth is a decline in antioxidant buffering capacity. According to Betteridge's definition, the two reasons for pathology may be excess oxidants and a weak defence system [5]. With age, some cells are no longer protected by free-radical defences and cannot repair damage caused by oxygen. Degenerative lesions are thus manifestations of reduced resistance to biochemical injury.

A sixthly, there are connections to oxidative stress and inflammation. Liguori and others have associated oxidative stress with inflammation and other organ diseases at the level of organs [6]. Increased production of oxidants occurs in inflammation; thus, there is an amplification of the inflammatory signal and damage to tissues. At this time, the degenerative lesions may spread more rapidly and are difficult to treat.

A seventh mechanism is the persistence of microenvironmental deterioration. Oxidative processes damage both the internal structure of cells and the components of the extracellular matrix and blood vessels [7-8]. Tissue Environment Oxidative modification leads to a loss of cell-cell communication, reduced plasticity and impaired repair coordination. Thus, the lesion spreads in an injured biological environment rather than in a normal one.

The above mechanisms are not independent. The causes of sustained damage to mitochondria, abnormal signal transduction, an impaired antioxidant system, excessive inflammation and a damaged microenvironment in oxidative stress at the molecular level include all these factors. Therefore, the development of age-related degenerative lesions is best understood as a redox-regulated process rather than as independent damage in a single cell compartment.

4. RELEVANCE TO MAJOR AGE-RELATED DEGENERATIVE CONDITIONS

Oxidative stress is relatively more pronounced in the context of age-related decline of all diseases. Neurodegenerative diseases are the typical ones. Uttara and others have identified oxidative stress as a cause of neurodegenerative diseases and have also linked neuronal damage to an excess of oxidative load and reduced antioxidant defence [9]. Neurons have relatively high metabolic demands and are

more dependent on mitochondrial function, as well as having poor regeneration abilities. Therefore, oxidative stress may have damaged the neurons and led to the extended degeneration of these neurons.

Another kind is blood vessel ageing. Madamanchi, Vendrov and Runge have shown that oxidative stress is closely associated with vascular diseases, and thus, due to endothelial dysfunction, inflammation and damage to blood vessels occur [10]. In older adults, the changes mentioned above are closely related to degenerative vascular lesions, reduced nitric oxide bioavailability, remodelling of the vascular wall, and chronic impairment of vascular homeostasis.

A more recent synthesis has shown that oxidative stress in ageing diseases is very complex and not uniform. Płóciniczak and others believe that oxidative stress in age-related diseases of humans is closely associated with metabolic disorders, inflammatory pathways, dysregulated lipid metabolism and altered protective enzyme systems [11]. Thus, the risk of oxidative damage will not be attributed to a single reason in the future. It should be viewed as one of the many links in the pathological environment for the occurrence, spread and development of degenerative lesions.

This cross-disease relevance has a serious problem. Age-related changes cannot be fully accounted for by local histological alterations. The same kind of lesion may have different courses due to mitochondrial efficiency, systemic inflammation, metabolic conditions and antioxidant capacity. Oxidative stress is damaging to all parts of the body in old age.

The same reason is why therapeutic interpretation is also difficult. Oxidants are required for physiological signals and tissue damage; thus, they cannot be removed arbitrarily and assumed to have returned to the normal state. Thus, an ideal record of the process of degeneration should differentiate between harmful oxidative overload and necessary redox reactions, and focus on restoring balance rather than suppressing oxidants.

Given that it is widely used, oxidative stress has been often associated with multiple diseases in older people. When multiple chronic degenerative diseases occur simultaneously, they often share inflammatory stress, mitochondrial dysfunction and impaired blood vessels. Oxidative stress helps to expose the common biological foundation for interaction and amplification of these seemingly independent lesions in the same ageing organism.

5. INTERPRETIVE IMPLICATIONS FOR THE STUDY OF DEGENERATIVE LESIONS

A typical application of the above studies is to view oxidative stress as both a cause and a condition of disease. Harman's early and later formulations are still useful because they focus on the cumulative injury in life [1, 2]. Later studies have also revealed that oxidative stress occurs due to causes other than free-radical generation. It also includes disorganised signalling, maladaptive cellular responses and a failure of coordinated protection [3, 4].

The extended interpretation now changes how age-related degenerative lesions are analysed. Besides oxidative stress, other research has also explored other types of damage caused by redox imbalance, such as changes in blood vessels and nerves, injury sites, and inflammation at these locations. Valko and Halliwell have provided the foundation for research on how oxidative reactions damage essential biomolecules and alter the chemical environment that promotes the spread of damage [7, 8].

Secondly, the progression of lesions is not always in a straight line. Oxidative stress may be partially compensated for over a long period, and then when the antioxidant reserve is depleted, mitochondrial dysfunction occurs, or inflammation increases, it will be exacerbated. Betteridge's framework and Liguori's synthesis work together to explain this change by showing that imbalance occurs when the protective system can no longer control the oxidant pressure [5, 6]. This helps explain why many degenerative lesions accelerate in old age and do not progress at a constant rate.

A third is that therapeutic reasoning. Based on the existing studies of neurodegenerative and vascular diseases, the concept of antioxidant thinking should move beyond the simple scavenging model and address oxidative stress in signalling, metabolism, and tissue-specific vulnerability [9, 10]. Therefore, the required modification will not be limited to chemical scavenging of free radicals. Continue to carry out redox communication in the body and reduce harmful overload to help damaged tissues heal.

The fourth is a method. Metabolites have recently shown that oxidative stress in age-related diseases is associated with multiple biomarkers, enzymatic systems and interacting pathological networks, rather than a single universal index [11]. Scholarly analysis will, therefore, study degenerative lesions within an integrated redox framework rather than as isolated biochemical snapshots. This way is more suitable for the complexity of old tissue.

The fifth type is abstract. Oxidative stress can help explain why the different age-related lesions share a common background but are not biologically the same. The same redox imbalance can be manifested in different ways in vessels, neurons, connective tissues and other organs with distinct functions and structures, and thus will lead to different damage patterns. Oxidative stress is thus a general framework, but it is not all-encompassing.

The last is a problem of causality. Another cause of the degenerative damage is oxidative stress. That is to say, it is a type of force that increases the susceptibility of the body, accelerates the damage caused by injury, and lowers the threshold for functional failure in aged tissues. Thus, the idea will still be scientifically feasible and not overly general in scope.

Together, these proposals suggest that oxidative stress is still one of the most likely reasons for age-related decline at present. Its necessity does not stem from a single major event but from the extended disturbance of redox homeostasis, repair ability and cellular coordination that incrementally degrade ageing tissues.

6. CONCLUSION

Oxidative stress is associated with various pathological processes in the general biological system of ageing-related diseases, such as molecular damage, mitochondrial dysfunction, dysregulation of signalling pathways, inflammation and impaired tissue repair. It has been found to occur in various tissues and disease conditions; therefore, it is now recognized as one of the primary paths of age-related deterioration.

Oxidative stress should not be reduced to just an increase in free radicals, this paper has proposed. It can be viewed as a dynamic disturbance of redox homeostasis that increases tissue damage and promotes the development of degeneration over time.

Therefore, in the study of age-related degenerative lesions, oxidative stress should be continuously analysed as both a cause of pathology and a general condition in the body. Thus, we can provide an all-encompassing reason for the gradual onset of degeneration and organ-system-wide interactions in old age, as well as difficulties in reversing this process.

REFERENCES

[1] Harman, D. (1956). Aging: A theory based on free radical and radiation chemistry. Journal of Gerontology, 11(3), 298-300.

[2] Harman, D. (1992). Free radical theory of aging. Mutation Research/DNAging, 275(3-6), 257-266.

[3] Finkel, T., & Holbrook, N. J. (2000). Oxidants, oxidative stress and the biology of ageing. Nature, 408(6809), 239-247.

[4] Finkel, T. (2003). Oxidant signals and oxidative stress. Current Opinion in Cell Biology, 15(2), 247-254.

[5] Betteridge, D. J. (2000). What is oxidative stress?. Metabolism, 49(2, Suppl. 1), 3-8.

[6] Liguori, I., Russo, G., Curcio, F., Bulli, G., Aran, L., Della-Morte, D., Gargiulo, G., Testa, G., Cacciatore, F., Bonaduce, D., & Abete, P. (2018). Oxidative stress, aging, and diseases. Clinical Interventions in Aging, 13, 757-772.

[7] Valko, M., Leibfritz, D., Moncol, J., Cronin, M. T. D., Mazur, M., & Telser, J. (2007). Free radicals and antioxidants in normal physiological functions and human disease. The International Journal of Biochemistry & Cell Biology, 39(1), 44-84.

[8] Halliwell, B. (2007). Biochemistry of oxidative stress. Biochemical Society Transactions, 35(5), 1147-1150.

[9] Uttara, B., Singh, A. V., Zamboni, P., & Mahajan, R. T. (2009). Oxidative stress and neurodegenerative diseases: A review of upstream and downstream antioxidant therapeutic options. Current Neuropharmacology, 7(1), 65-74.

[10] Madamanchi, N. R., Vendrov, A., & Runge, M. S. (2005). Oxidative stress and vascular disease. Arteriosclerosis, Thrombosis, and Vascular Biology, 25(1), 29-38.

[11] Płóciniczak, A., Bukowska-Olech, E., & Wysocka, E. (2025). The complexity of oxidative stress in human age-related diseases—A review. Metabolites, 15(7), 479.