

**OXIDATIVE STRESS: MODERN UNDERSTANDING AND AN AYURVEDIC
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ABSTRACT

Oxidative stress is a disturbance of redox homeostasis in which reactive oxygen species (ROS) and related reactive species exceed the capacity of antioxidant and repair systems. ROS arise during normal cellular metabolism and may increase with inflammation, radiation, smoking, pollution, mitochondrial dysfunction and other stressors. Excessive reactive species can modify lipids, proteins and nucleic acids, impair mitochondrial function and contribute to cellular senescence and chronic disease. Ayurveda does not describe a direct one-to-one equivalent of the modern biochemical term oxidative stress. This review therefore considers oxidative stress through the interacting concepts of Dosha, Agni, Ama, Dhatu, Ojas, Jara, Ahara, Nidra, Vihara and Rasayana. Vata is especially relevant to age-associated depletion and degenerative change; Pitta and Agni are relevant to metabolism and inflammatory or heat-related processes; Kapha may be involved when impaired metabolism, accumulation or obstruction is present. These are conceptual correlations, not direct biochemical equivalences. The article outlines potential links between redox imbalance, mitochondrial dysfunction, molecular damage, ageing, diet, sleep and Ayurvedic preventive principles.

KEYWORDS: Oxidative stress; reactive oxygen species; Ayurveda; Agni; Ama; Dosha; Dhatu; Ojas; Rasayana; ageing.**1. INTRODUCTION**

Oxidative stress is an important concept in modern physiology and pathology. Reactive oxygen species (ROS) are continuously generated during cellular metabolism, particularly during mitochondrial electron transfer. At physiological concentrations, ROS participate in cell signalling, host defence, adaptation and regulation of cellular processes. Oxidative stress develops when oxidant production and redox signalling become excessive or when antioxidant and repair capacity is insufficient.

Biologically relevant ROS include superoxide anion ($O_2^{\bullet-}$), hydrogen peroxide (H_2O_2) and the hydroxyl radical ($\bullet OH$). Reactive nitrogen species also participate in redox biology. Excessive reactive species can modify membrane lipids, proteins and DNA. The consequences depend on the amount, duration, location and cellular context of the oxidative challenge.

This review presents the modern understanding of oxidative stress alongside an Ayurvedic conceptual interpretation, with emphasis on maintaining a clear distinction between biochemical mechanisms and classical Ayurvedic terminology.

2. AYURVEDIC PERSPECTIVE ON OXIDATIVE STRESS

Ayurveda does not provide a direct classical synonym for oxidative stress. For academic discussion, it may be considered a multifactorial process that can be interpreted through Agni-vaishamya, Ama formation where applicable, Dosha prakopa, Srotodushti, Dhatu dushti or kshaya, and reduced Bala/Ojas. These concepts should not be treated as direct equivalents of ROS or measurable oxidative-stress markers.

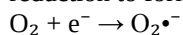
Vata has particular relevance to ageing, tissue depletion, dryness, degeneration and loss of functional reserve.

Pitta is relevant to metabolic transformation, Agni and inflammatory or heat-related processes. Kapha supports stability, structure and lubrication, but may become involved when heaviness, impaired metabolism or accumulation is prominent. The relative involvement of Doshas depends on the causative factors and clinical context; oxidative stress should not be assigned to one Dosha in every case.

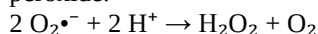
Disturbed diet, irregular sleep, excessive exertion, chronic stress, environmental exposures and impaired metabolic processing can be discussed as factors that disturb homeostasis. Their Ayurvedic interpretation may involve Agni-vikriti, Dosha prakopa and impaired Dhatu nourishment, depending on the circumstances.

3. FORMATION OF REACTIVE OXYGEN SPECIES

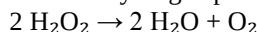
ROS arise from endogenous and exogenous sources. Mitochondrial electron transport is an important physiological source; during electron transfer, a small proportion of oxygen may undergo one-electron reduction to form superoxide.



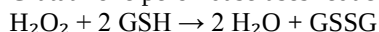
Superoxide dismutase converts superoxide to hydrogen peroxide:



Hydrogen peroxide can be removed by catalase, glutathione peroxidase and related systems. Catalase converts hydrogen peroxide into water and oxygen:



Glutathione peroxidase uses reduced glutathione (GSH):



Under appropriate conditions, hydrogen peroxide can participate in reactions that generate the highly reactive hydroxyl radical. Antioxidant systems do not eliminate all ROS; they regulate redox balance and prevent uncontrolled oxidative damage.

From an Ayurvedic perspective, reactive oxidants may be discussed conceptually in relation to Agni and Ama. Charaka describes Agni as essential for digestion, metabolism, nourishment, strength, health, Ojas and Tejas (Charaka Samhita, Chikitsa Sthana 15/3–4). Impairment of Agni is associated with improper digestion and transformation and with Ama (Charaka Samhita, Chikitsa Sthana 15/44–45; Vimanasthana 2/10). Ama may provide a conceptual framework for discussing improper transformation, but it should not be equated directly with ROS.

4. ANTIOXIDANT DEFENCE SYSTEM

The antioxidant Defence system consists of enzymatic and non-enzymatic components. Important enzymatic antioxidants include

- Superoxide dismutases (SOD)
- Catalase
- Glutathione peroxidases (GPx)
- Peroxiredoxins and related redox systems

Important non-enzymatic antioxidants and redox buffers include glutathione, vitamins C and E, carotenoids and plant-derived polyphenols. Vitamin E helps protect membrane lipids from chain-propagating lipid peroxidation, while vitamin C participates in aqueous-phase antioxidant reactions and can help regenerate other antioxidants. The goal is maintenance of redox homeostasis rather than complete elimination of ROS.

In Ayurveda, Rasayana, Dhatu-poshana, Ojas and Vyadhikshamatva provide a conceptual framework for discussing physiological resilience and natural defence. Charaka describes Rasayana as promoting longevity, health, youthfulness and quality of body tissues (Charaka Samhita, Chikitsa Sthana 1/1/7–8). Sushruta describes Ojas as the essence of the Dhatus and associates it with Bala (Sushruta Samhita, Sutrasthana 15/19). These concepts may be discussed alongside antioxidant defence, but they are not biochemical equivalents.

5. FACTORS THAT MAY INCREASE OXIDATIVE STRESS

Oxidative stress may increase when ROS generation rises, antioxidant capacity falls, or both occur. Relevant contributors include:

- Chronic inflammation and infection
- Immune-cell activation
- Ionising radiation
- Cigarette smoke and other combustion products
- Air pollution and environmental oxidants
- Mitochondrial dysfunction and metabolic disturbances
- Poor dietary patterns
- Persistent psychological or physiological stress
- Irregular or insufficient sleep

Activated immune cells generate ROS as part of host defence. When inflammation becomes prolonged, repeated ROS generation can increase oxidative burden and consume antioxidant resources. Radiation can generate reactive species through interactions with cellular water and other molecules. Smoking introduces oxidants and reactive compounds that can increase oxidative damage.

From an Ayurvedic perspective, Ahara and Vihara are important areas of consideration. Dietary and lifestyle factors should be evaluated in relation to an individual's digestive capacity, Dosha status, sleep, activity and environmental context.

6. MITOCHONDRIAL DYSFUNCTION AND ATP PRODUCTION

Mitochondria generate most cellular ATP through oxidative phosphorylation. Electrons derived from nutrient metabolism enter the electron transport chain, creating a proton gradient across the inner mitochondrial membrane. ATP synthase uses this gradient to synthesize ATP.

$\text{NADH/FADH}_2 \rightarrow \text{Electron Transport Chain} \rightarrow \text{Proton Gradient} \rightarrow \text{ATP}$

Oxidative damage can affect mitochondrial lipids, proteins and mitochondrial DNA. Mitochondrial dysfunction can reduce the efficiency of oxidative phosphorylation and impair cellular energy production. The relationship is bidirectional: mitochondria can generate ROS, while mitochondrial damage can alter redox signalling and cellular metabolism.

Conceptually, mitochondrial dysfunction may be discussed through Agni and Dhatvagni, which relate to transformation and metabolism. Charaka describes Agni as important for nourishment, strength, Ojas and Tejas (Charaka Samhita, Chikitsa Sthana 15/3–4). Disturbed Agni/Dhatvagni may be considered in relation to improper tissue nourishment, while Vata may be discussed in relation to movement and regulation of physiological activities. These are interpretive correlations, not direct cellular mechanisms described in classical texts.

7. OXIDATIVE DAMAGE TO DNA

ROS can oxidize DNA bases and damage the sugar-phosphate backbone. Oxidized bases, abasic sites and single- or double-strand breaks may occur. One well-characterized oxidative DNA lesion is 8-oxo-7,8-dihydroguanine (8-oxoG). This lesion can mispair with adenine during DNA replication, increasing the risk of a G:C $\rightarrow$ T:A transversion if it is not repaired correctly. DNA-repair systems, including base-excision repair, help reduce the persistence of oxidative DNA lesions. Persistent damage can contribute to genomic instability, cellular dysfunction and senescence.

8. PROTEIN AND LIPID DAMAGE

Oxidative modification can alter protein structure, enzyme activity, folding and turnover. Damaged proteins may be removed by cellular quality-control systems; if damage exceeds repair and clearance capacity, dysfunctional proteins can accumulate. ROS can also initiate lipid peroxidation, particularly in polyunsaturated fatty acids. Lipid peroxidation changes membrane properties and generates secondary reactive products that can further modify proteins and DNA.

Protein oxidation and lipid peroxidation may be conceptually correlated with impairment of the structural and functional integrity of Dhatu and Srotas. Such impairment can be discussed through Kha-vaigunya, a framework for tissue vulnerability. Charaka describes localization of circulating Rasa and Vikriti at a site of Kha-vaigunya (Charaka Samhita, Chikitsa Sthana 15/37), while Sushruta describes disease manifestation where aggravated Doshas lodge at a site of Kha-vaigunya (Sushruta Samhita, Sutrasthana 24/10). This is an interpretive pathological correlation rather than a direct equivalence.

9. OXIDATIVE STRESS AND AGEING

Ageing is multifactorial and involves changes in cellular maintenance, mitochondrial function, genomic stability, inflammation, proteostasis and tissue repair. Oxidative stress is one contributor rather than a complete explanation of ageing. Cumulative molecular damage and altered redox regulation may impair cellular function, while mitochondrial dysfunction, persistent inflammation and cellular senescence can interact.

From an Ayurvedic perspective, Vriddhavastha/Jara is associated with progressive degenerative change and Vata predominance. Classical descriptions include dryness, wrinkling, reduced strength and progressive Dhatu depletion. Premature ageing may be discussed in relation to Vata and Pitta aggravation and unsuitable diet or lifestyle, while avoiding the claim that a single Dosha or Rasa alone explains all ageing-related changes.

10. DIET, RASA AND OXIDATIVE STRESS

Diet can influence oxidative balance through nutrient composition and overall metabolic effects. Foods containing vitamin C, vitamin E, carotenoids, polyphenols and other phytochemicals can contribute to antioxidant defence. In Ayurveda, dietary substances are assessed through Rasa, Guna, Virya and Vipaka, which help explain their traditional effects on Dosha and physiological balance.

The source framework proposes that Tikta, Kashaya and appropriate Madhura Rasa may be discussed in relation to Pitta pacification, while excessive Amla, Lavana and Katu intake may be considered in relation to Pitta aggravation. This should be presented as a traditional interpretive framework, not as proof that these tastes directly increase or decrease ROS. The antioxidant potential of a food depends on its chemical constituents and supporting scientific evidence.

Amalaki is described as Amla-pradhana in Rasa, Shita in Virya and Madhura in Vipaka; Draksha is described as Madhura-pradhana with Amla anurasa, Shita Virya and Madhura Vipaka. Both have been investigated for antioxidant-related phytochemicals. Their modern biological effects cannot be inferred solely from Rasa, Virya or Vipaka.

11. IRREGULAR SLEEP AND OXIDATIVE STRESS

Sleep supports circadian regulation, metabolic recovery, immune regulation and cellular maintenance. Irregular or insufficient sleep can disturb circadian rhythms and is associated with altered metabolic and inflammatory signalling. These changes may increase oxidative burden or reduce the effectiveness of antioxidant and repair processes.

A proposed pathway is: irregular or insufficient sleep $\rightarrow$ circadian and metabolic disruption $\rightarrow$ altered inflammatory signalling and mitochondrial stress $\rightarrow$

increased oxidative burden and/or reduced antioxidant defence → damage to lipids, proteins and DNA. The goal is regular, adequate, good-quality sleep rather than simply increasing sleep duration.

12. AYURVEDIC PATHOGENETIC INTERPRETATION

A conceptual Ayurvedic sequence for discussing oxidative stress may be presented as:

Nidana → Agni-vaishmya → impaired metabolic processing and, where applicable, Ama formation → Dosha prakopa → Srotodushti → impaired Dhatu-poshana → Dhatu dushti or kshaya → reduced Bala/Ojas and tissue resilience → progressive functional disturbance.

This sequence should be adapted to the particular disease rather than applied mechanically. Ama is not a chemical synonym for ROS or oxidative products, and Srotodushti is not equivalent to a specific modern cellular pathway. In age-related degeneration, Vata and Dhatu kshaya are especially relevant concepts. Pitta/Agni may be relevant where inflammation or heat-related tissue injury is prominent, while Kapha may be involved where accumulation or impaired metabolism contributes to the clinical picture.

13. RASA, DHATU AND PREMATURE AGEING

For premature ageing and skin changes, the Ayurvedic discussion can be organized around Rasa Dhatu, subsequent Dhatu nourishment and tissue maintenance. Rasa provides the nutritional basis for subsequent Dhatu formation, while healthy tissue nourishment and Ojas are associated with strength and resilience. Wrinkling and dryness may be discussed in relation to Vata predominance and Ruksha/Khara qualities. Pitta-related factors may be relevant when heat, inflammation or sun-related injury predominates. Academically, fine lines should not be assigned to a single Rasa defect; age, environment, lifestyle, Dosha and tissue nourishment may interact.

14. AYURVEDIC APPROACH: AHARA AND VIHARA

An Ayurvedic preventive approach emphasizes preservation of Agni, suitable Ahara, regular Nidra, balanced activity, mental wellbeing and avoidance of excessive or unsuitable exposures. Relevant principles include:

- Regular and suitable meals according to digestive capacity
- Adequate hydration and a varied, nutrient-dense diet
- Avoidance of persistent dietary excesses and highly processed dietary patterns
- Regular sleep-wake timing
- Appropriate physical activity without excessive exertion
- Stress management and maintenance of mental equilibrium
- Protection from avoidable environmental exposures

- Suitable Dinacharya and seasonal adaptation where appropriate

These measures may support metabolic health, circadian stability, inflammatory balance and normal antioxidant defence. They should be presented as general health-supporting measures, not as a guaranteed treatment for oxidative stress.

15. RASAYANA AND ANTIOXIDANT SUPPORT

Rasayana is an Ayurvedic approach concerned with preservation of health, strength, tissue nourishment, vitality and healthy ageing. Modern research has investigated antioxidant, anti-inflammatory, immunomodulatory and other biological effects of selected Rasayana plants and formulations. Amalaki contains vitamin C and polyphenolic compounds; Guduchi and Ashwagandha have also been studied. However, laboratory antioxidant activity does not automatically establish that a preparation prevents or reverses human ageing. Clinical evidence varies by herb, formulation, dose, population and study design. Rasayana should therefore be presented as an area for further research into redox balance, cellular resilience and healthy ageing, rather than as a guaranteed anti-ageing treatment.

16. INTEGRATED CONCEPTUAL MODEL

Modern pathway: physiological or excessive ROS generation → redox imbalance → lipid, protein and DNA oxidation → mitochondrial dysfunction and altered signalling → cellular senescence and impaired tissue function → contribution to chronic disease and ageing.

Ayurvedic conceptual pathway: Nidana or unsuitable Ahara-Vihara → Agni-vaishmya and, where applicable, Ama → Dosha prakopa → Srotodushti → impaired Dhatu nourishment → Dhatu dushti/kshaya and reduced Ojas/Bala → degeneration and reduced tissue resilience.

Diet, sleep, stress, inflammation, environmental exposure and ageing can influence both redox homeostasis and Ayurvedic concepts of Agni, Dosha and Dhatu maintenance. The two systems may be compared for research purposes while preserving their distinct terminology and epistemology.

17. CONCLUSION

Oxidative stress is a disturbance of redox homeostasis involving excessive or poorly controlled reactive species relative to cellular defence and repair. It can affect lipids, proteins, DNA and mitochondria and contribute to cellular senescence and chronic disease processes. Ayurveda offers a multidimensional conceptual framework involving Dosha, Agni, Ama, Srotas, Dhatu, Ojas, Ahara, Nidra, Vihara and Rasayana. Vata is particularly relevant to age-related degeneration and Dhatu kshaya, while Pitta/Agni is relevant to metabolism and inflammatory processes; Kapha may be involved according to patterns of accumulation and metabolic

function. These correlations should be treated as conceptual bridges, not as claims that oxidative stress is directly described by a single classical Ayurvedic term.

Future integrative research may examine measurable oxidative-stress markers alongside Ayurvedic variables such as Prakriti, Agni, Dosha assessment, Dhātu assessment and quality of life.

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