INTERNATIONAL JOURNAL OF CURRENT RESEARCH IN CHEMISTRY AND PHARMACEUTICAL SCIENCES
(p-ISSN: 2348-5213: e-ISSN: 2348-5221)
www.ijcrcps.com
(A Peer Reviewed, Referred, Indexed and Open Access Journal)
DOI: 10.22192/ijcrcps Coden: IJCROO(USA) Volume 11, Issue 8- 2024

Review Article

DOI: http://dx.doi.org/10.22192/ijcrcps.2024.11.08.005

Role of Autophagy in Modulating Oxidative Stress in Sickle Cell Disease: A Narrative Review

***Emmanuel Ifeanyi Obeagu**
Department of Medical Laboratory Science, Kampala International University, Uganda
*Corresponding authour: Emmanuel Ifeanyi Obeagu, Department of Medical Laboratory Science, Kampala International University, Uganda, emmanuelobeagu@yahoo.com,
ORCID: 0000-0002-4538-0161

Abstract

Autophagy, a fundamental cellular process responsible for degrading and recycling damaged components, plays a crucial role in modulating oxidative stress, which is a key factor in Sickle Cell Disease (SCD). In SCD, the sickling of red blood cells (RBCs) leads to increased production of reactive oxygen species (ROS), contributing to cellular damage and disease complications. This review explores the complex interplay between autophagy and oxidative stress in SCD, highlighting how autophagy influences RBC function, hemolysis, and disease progression. The dual role of autophagy in SCD is evident; while it can protect against oxidative stress by removing damaged cellular components, dysregulated autophagy may exacerbate disease pathology. Enhanced autophagic activity may help reduce oxidative damage and improve RBC health, whereas impaired autophagy can lead to increased oxidative stress and hemolysis. This review examines how autophagy affects RBC function, contributes to hemolysis, and impacts disease outcomes in SCD.

Keywords: Autophagy, Oxidative Stress, Sickle Cell Disease, Hemoglobin S, Cellular Homeostasis

Introduction

Sickle Cell Disease (SCD) is a genetic hematological disorder caused by a single point mutation in the β-globin gene, leading to the production of abnormal hemoglobin S (HbS). This mutation results in the sickling of red blood cells (RBCs) under low oxygen conditions, causing a range of pathological complications. One of the significant consequences of sickling is the increased generation of reactive oxygen species (ROS), which contributes to oxidative stress and cellular damage. Autophagy, a crucial cellular process responsible for degrading damaged organelles and proteins, plays a significant role in managing oxidative stress.[1-3] Autophagy is a dynamic process that involves the formation of autophagosomes to engulf damaged cellular components, which are then delivered to lysosomes for degradation. This process is essential for maintaining cellular homeostasis, particularly in the context of oxidative stress. In SCD, the abnormal sickling of RBCs leads to chronic oxidative stress due to the continuous production of ROS. Autophagy can mitigate oxidative damage by removing oxidized proteins and damaged organelles, thereby protecting cells from further injury. However, the interplay between autophagy and oxidative stress in SCD is complex, with potential protective and detrimental effects.[4-6]In SCD, the sickling of RBCs results in a range of pathological events, including increased hemolysis and inflammation. The release of free hemoglobin and heme into the bloodstream exacerbates oxidative stress, leading to further cellular damage and inflammation. Autophagy is implicated in modulating these effects by managing the removal of damaged components and regulating the oxidative environment within cells. However, dysregulation of autophagy can exacerbate oxidative stress and contribute to disease complications. Understanding the balance between protective and detrimental roles of autophagy in SCD is crucial for developing targeted therapies.[7-9]

The role of autophagy in RBC function is particularly relevant in SCD. Autophagy influences the lifespan and functionality of RBCs by regulating the degradation of damaged cell components and maintaining cellular integrity. In SCD, the dysregulation of autophagy can impair RBC function and contribute to increased hemolysis. Research has shown that enhanced autophagic activity may reduce oxidative damage and improve RBC health, while impaired autophagy can exacerbate oxidative stress and hemolysis. Exploring how autophagy affects RBC function in the context of SCD provides insights into potential therapeutic approaches.[10-11] Hemolysis in SCD is a key feature of the disease and is influenced by oxidative stress and autophagy. The destruction of RBCs results in the release of hemoglobin and heme, further contributing to oxidative damage and inflammation. Autophagy plays a role in managing hemolysis by regulating the removal of damaged RBCs and maintaining cellular balance. Dysregulated autophagy can lead to increased hemolysis and exacerbate oxidative stress, highlighting the need for a better understanding of autophagy's role in SCD pathology.[12-13] The clinical implications of autophagy in SCD are significant, with potential impacts on disease management and therapeutic interventions. Targeting autophagy could provide new avenues for mitigating oxidative stress and improving patient outcomes. Therapeutic strategies, such as pharmacological agents that modulate autophagy pathways or gene therapies to correct autophagy-related defects, hold promise for enhancing disease management. Further research into the precise mechanisms linking autophagy and oxidative stress in SCD is essential for developing effective treatments.[14-15]

Autophagy: Mechanisms and Functions

Autophagy is a highly regulated cellular process essential for maintaining cellular homeostasis by degrading and recycling damaged organelles, proteins, and other macromolecules. The process is crucial for cellular health and function, particularly under conditions of stress or damage. The primary mechanisms and functions of autophagy include initiation, formation of autophagosomes, fusion with lysosomes, and degradation of cellular components.[16-17] Autophagy begins with the initiation phase, where

the process is triggered by various cellular signals and stressors. The initiation is regulated by the ULK1 (Unc-51 Like Autophagy Activating Kinase 1) complex, which includes ULK1, ATG13, FIP200, and ATG101. These proteins respond to nutrient deprivation, oxidative stress, and other stimuli by activating the autophagy machinery. The activation of ULK1 leads to the formation of a phagophore, a membrane structure that will eventually develop into an autophagosome.[18-19] The phagophore expands and engulfs cytoplasmic material, including damaged organelles and proteins, to form an autophagosome. This membrane-bound vesicle is essential for the selective degradation of cellular components. The expansion of the phagophore involves several key proteins, including the ATG (Autophagy-related) family members, such as ATG5, ATG7, and LC3 (Microtubule-associated Protein 1 Light Chain 3). LC3 is converted to LC3-II during autophagosome formation and is used as a marker to monitor autophagy activity.[20-21] Once the autophagosome is fully formed, it fuses with a lysosome to create an autolysosome. This fusion process involves a set of proteins, including SNARE (Soluble N-ethylmaleimide-sensitive factor attachment protein receptor) complexes, which mediate the merging of the autophagosome and lysosome membranes. The lysosome contains various hydrolytic enzymes that degrade the contents of the autophagosome. This step is crucial for the effective breakdown and recycling of cellular materials.[22-23]

In the autolysosome, the enclosed materials are subjected to acidic conditions and enzymatic degradation. The breakdown products, including amino acids, lipids, and sugars, are released back into the cytoplasm and used for cellular processes such as energy production and biosynthesis. This recycling function is vital for maintaining cellular homeostasis, particularly during periods of stress or nutrient deprivation.[24-25] Autophagy is regulated by various signaling pathways that respond to changes in cellular conditions. The mTOR (mechanistic target of rapamycin) pathway is a central regulator of autophagy, inhibiting the process under nutrient-rich conditions and promoting it during nutrient deprivation. Other regulatory pathways include the AMPK (AMP-activated protein kinase) pathway, which responds to energy stress, and the p53 pathway, which is involved in cellular stress responses and apoptosis.[26-27] Dysregulation of autophagy has been implicated in various diseases, including cancer, neurodegenerative disorders, and cardiovascular diseases. In the context of Sickle Cell Disease (SCD), autophagy plays a dual role by both protecting against and contributing to disease pathology. Proper regulation of autophagy is essential for managing oxidative stress, cellular damage, and inflammation associated with SCD.[28-29]

Oxidative Stress in Sickle Cell Disease

Oxidative stress is a central feature of Sickle Cell Disease (SCD), a genetic disorder characterized by the production of abnormal hemoglobin S (HbS). The sickling of red blood cells (RBCs) and the subsequent pathological events are closely linked to the generation and accumulation of reactive oxygen species (ROS). These ROS contribute to a range of cellular and systemic complications, exacerbating the disease's severity and impacting patient outcomes.[30-31] In SCD, the sickling of RBCs under low oxygen conditions leads to the release of free hemoglobin and heme into the bloodstream. Both free hemoglobin and heme are potent sources of oxidative stress. Free hemoglobin can be broken down into methemoglobin and other oxidizing agents, which in turn generate ROS. Additionally, the heme group, which contains iron, can catalyze the production of hydroxyl radicals through Fenton reactions, further increasing oxidative damage. The continuous cycle of RBC sickling, hemolysis, and ROS generation creates a chronic state of oxidative stress.[32-33] Oxidative stress in SCD affects various cellular components, including lipids, proteins, and nucleic acids. Lipid peroxidation leads to the formation of malondialdehyde (MDA) and other reactive aldehydes, which can damage cell membranes and contribute to RBC membrane instability. Protein oxidation can impair enzyme function and disrupt cellular signaling pathways, leading to further cellular dysfunction. DNA damage caused by

ROS can result in mutations and genomic instability, potentially affecting cellular health and function.[34-35] The impact of oxidative stress on RBCs is profound. Oxidative damage to the RBC membrane can lead to increased cell fragility and premature hemolysis. The loss of functional RBCs contributes to anemia, which is a hallmark of SCD. Additionally, oxidative stress can exacerbate sickling by promoting the oxidation of hemoglobin, further increasing the tendency of RBCs to sickle under low oxygen conditions. The combined effects of oxidative stress and hemolysis create a vicious cycle that exacerbates disease symptoms and complications.[36-37]

Beyond RBCs, oxidative stress in SCD affects various organ systems. The increased ROS levels contribute to endothelial dysfunction, promoting vascular inflammation and impairing blood flow. This can lead to vaso-occlusive crises, which are characterized by severe pain and organ damage. Oxidative stress also impacts the kidneys, liver, and other organs, contributing to multi-organ damage and affecting overall health and quality of life.[38-39] Oxidative stress and inflammation are closely interconnected in SCD. ROS generated during oxidative stress can activate inflammatory pathways, leading to the release of pro-inflammatory cytokines and chemokines. This exacerbates the inflammatory response, further contributing to tissue damage and disease complications. The interplay between oxidative stress and inflammation highlights the need for strategies that address both factors to manage SCD effectively.[39-40] In response to oxidative stress, cells have evolved various antioxidant defense mechanisms to mitigate damage. These include enzymatic antioxidants such as superoxide dismutase (SOD), catalase, and glutathione peroxidase, as well as non-enzymatic antioxidants like glutathione and vitamin E. In SCD, these defense mechanisms can become overwhelmed due to the excessive production of ROS. Enhancing antioxidant defenses or supplementing with antioxidants may offer therapeutic benefits by reducing oxidative damage and improving cellular health.[41]

Autophagy and Red Blood Cell Function

Autophagy is a vital cellular process that involves the degradation and recycling of damaged organelles, proteins, and other cellular components. In the context of red blood cells (RBCs), autophagy plays a crucial role in maintaining cell function and integrity, particularly under conditions of stress or damage.During erythropoiesis, or the production of RBCs, autophagy is essential for the proper maturation of red blood cell precursors. Early in erythropoiesis, developing erythroblasts rely on autophagy to remove excess organelles, such as mitochondria and the endoplasmic reticulum, to form mature enucleated RBCs. This process is critical for the transition from nucleated erythroblasts to reticulocytes, which then mature into functional RBCs. Proper autophagic activity ensures that RBCs are adequately prepared to perform their oxygen-carrying functions efficiently.[42-44] In mature RBCs, which lack organelles such as mitochondria, autophagy still plays a significant role in maintaining cell integrity and function. Autophagy helps manage oxidative stress by degrading damaged proteins and lipids, thus preventing the accumulation of harmful byproducts that could impair RBC function. This is particularly important in Sickle Cell Disease, where oxidative stress is elevated due to the sickling of RBCs and the associated hemolysis. Effective autophagy helps protect RBCs from oxidative damage and supports their longevity and functionality.[45-46] The lifespan of RBCs is tightly regulated, and autophagy is a key factor in this regulation. In response to stress or damage, autophagy helps remove damaged components and reduces cellular stress, contributing to the overall health and longevity of RBCs. Disruptions in autophagy can lead to increased oxidative stress, reduced RBC lifespan, and enhanced hemolysis. In Sickle Cell Disease, where RBCs are subjected to continuous stress due to sickling and hemolysis, autophagic mechanisms can influence disease progression and severity.[47-48] Dysregulation of autophagy can have significant implications for RBC function and overall health. In Sickle Cell Disease, altered autophagy can exacerbate oxidative stress and

contribute to increased hemolysis and inflammation. For instance, impaired autophagy may lead to the accumulation of damaged proteins and lipids, further compromising RBC integrity and function.[49] The interplay between autophagy and oxidative stress is crucial for maintaining RBC function. Autophagy can mitigate oxidative damage by degrading oxidized proteins and damaged cellular components, thereby reducing the overall burden of oxidative stress. Conversely, excessive oxidative stress can impair autophagic activity, creating a vicious cycle that exacerbates cellular damage. In Sickle Cell Disease, where oxidative stress is a prominent feature, effective regulation of autophagy is essential for managing its impact on RBCs.[50]

Role of Autophagy in Sickle Cell Pathophysiology

Autophagy, a cellular process essential for degrading and recycling damaged cellular components, plays a significant role in the pathophysiology of Sickle Cell Disease (SCD). This genetic disorder, characterized by the production of abnormal hemoglobin S (HbS), leads to the sickling of red blood cells (RBCs) and subsequent complications. The role of autophagy in SCD encompasses various aspects, including cellular stress responses, oxidative damage, and the progression of disease manifestations.During erythropoiesis, the formation of mature RBCs from erythroblasts requires the removal of organelles through autophagy. This process ensures that RBCs are enucleated and functional. In Sickle Cell Disease, the sickling of RBCs and their premature destruction can disrupt this delicate balance. If autophagy is impaired, the removal of damaged organelles may be compromised, potentially affecting RBC maturation and function. This disruption can exacerbate the already challenging environment of SCD by contributing to further RBC dysfunction and hemolysis.[51] Sickle Cell Disease is characterized by elevated oxidative stress due to the sickling process and the release of free hemoglobin and heme into the bloodstream. Autophagy plays a crucial role in managing oxidative stress by degrading oxidized proteins and damaged lipids. In SCD, the excessive generation of reactive oxygen species (ROS) can overwhelm the autophagic system, leading to increased oxidative damage. Impaired autophagy may exacerbate oxidative stress, further contributing to RBC damage and the progression of disease complications.[52]

Hemolysis, or the destruction of RBCs, is a hallmark of Sickle Cell Disease. Autophagy is involved in the clearance of damaged or senescent RBCs, which is critical for maintaining RBC integrity and reducing hemolysis. In SCD, the constant sickling and subsequent hemolysis place additional stress on the autophagic system. Disruptions in autophagy can lead to the accumulation of damaged RBC components, which may further contribute to hemolysis and anemia. Understanding the role of autophagy in managing hemolysis can provide insights into potential therapeutic strategies for mitigating this aspect of SCD.[53] Autophagy has a complex relationship with inflammation. On one hand, autophagy can help mitigate inflammation by degrading inflammatory mediators and damaged cellular components. On the other hand, dysregulated autophagy can contribute to chronic inflammation. In Sickle Cell Disease, the ongoing oxidative stress and hemolysis lead to an inflammatory response. Impaired autophagy may exacerbate this inflammation, contributing to vaso-occlusive crises and other inflammatory complications. Exploring the interplay between autophagy and inflammation in SCD can reveal potential targets for therapeutic intervention.[5] Endothelial dysfunction is a significant factor in Sickle Cell Disease, contributing to vaso-occlusive events and organ damage. Autophagy plays a role in maintaining endothelial cell function by regulating cellular stress responses and repairing damaged components. In SCD, oxidative stress and inflammation can impair endothelial autophagy, leading to endothelial dysfunction. Enhancing autophagic activity in endothelial cells may help mitigate vascular complications and improve overall vascular health in SCD patients.[55]

Autophagy and Hemolysis in Sickle Cell Disease

Hemolysis, or the premature destruction of red blood cells (RBCs), is a fundamental characteristic of Sickle Cell Disease (SCD). This genetic disorder, caused by the mutation of the hemoglobin gene, leads to the production of abnormal hemoglobin S (HbS). Under low oxygen conditions, HbS promotes the sickling of RBCs, which contributes to their fragility and increased propensity for destruction. The process of hemolysis in SCD results in chronic anemia, elevated levels of free hemoglobin, and significant oxidative stress.Autophagy is a cellular process responsible for the degradation and recycling of damaged organelles and proteins. In the context of RBCs, autophagy is crucial for maintaining cell integrity and function. During erythropoiesis, autophagy helps in the maturation of RBCs by removing excess organelles and preparing the cells for their function in oxygen transport. In SCD, the sickling and subsequent hemolysis place additional stress on the autophagic system, which is tasked with managing the increased burden of damaged RBC components.[56] Disruption in autophagic processes can significantly impact RBC function and lifespan. In Sickle Cell Disease, impaired autophagy may lead to the accumulation of damaged proteins and lipids within RBCs. This accumulation exacerbates cell membrane instability and contributes to the increased rate of hemolysis. Additionally, defective autophagy can lead to the persistence of damaged or senescent RBCs, further aggravating the hemolytic process and contributing to anemia.The relationship between autophagy and oxidative stress is critical in the context of Sickle Cell Disease. Hemolysis releases free hemoglobin and heme into the bloodstream, which are potent sources of oxidative stress. Autophagy helps manage oxidative damage by degrading oxidized proteins and lipids. In SCD, excessive oxidative stress can overwhelm the autophagic system, leading to increased cellular damage and further hemolysis. The interplay between autophagy and oxidative stress is essential for understanding the pathophysiology of SCD and developing potential therapeutic strategies.[57]

Conclusion

Autophagy plays a pivotal role in the pathophysiology of Sickle Cell Disease (SCD), particularly in relation to hemolysis, oxidative stress, and overall red blood cell (RBC) function. The chronic hemolysis characteristic of SCD results from the sickling of RBCs and their subsequent premature destruction. This process places significant stress on the cellular mechanisms responsible for maintaining RBC integrity, with autophagy being a key player in managing this stress.

In healthy RBCs, autophagy facilitates the removal of damaged organelles and proteins, which is essential for maintaining cell function and longevity. In the context of SCD, however, the increased oxidative stress and hemolysis can overwhelm the autophagic system, leading to further cellular damage and exacerbation of disease symptoms. Impaired autophagy can contribute to the accumulation of damaged cellular components, promoting a vicious cycle of RBC damage and hemolysis.

References

1. Alenzi FQ, AlShaya DS. Biochemical and molecular analysis of the beta-globin gene on Saudi sickle cell anemia. Saudi Journal of Biological Sciences. 2019;26(7):1377-1384.
2. Obeagu EI, Ochei KC, Nwachukwu BN, Nchuma BO. Sickle cell anaemia: a review. Scholars Journal of Applied Medical Sciences. 2015;3(6B):224422-52.
3. Obeagu EI. Erythropoeitin in Sickle Cell Anaemia: A Review. International Journal of Research Studies in Medical and Health Sciences. 2020;5(2):22-28.
4. Obeagu EI. Sickle Cell Anaemia: Haemolysis and Anemia. Int. J. Curr. Res. Chem. Pharm. Sci. 2018;5(10):20-21.
5. Obeagu EI, Muhimbura E, Kagenderezo BP, Uwakwe OS, Nakyeyune S, Obeagu GU. An Update on Interferon Gamma and C Reactive

Proteins in Sickle Cell Anaemia Crisis. J Biomed Sci. 2022;11(10):84.
6. Sbodio JI, Snyder SH, Paul BD. Redox mechanisms in neurodegeneration: from disease outcomes to therapeutic opportunities. Antioxidants & Redox Signaling. 2019;30(11):1450-1499.
7. Kovacic P, Somanathan R. Redox processes in neurodegenerative disease involving reactive oxygen species. Current neuropharmacology. 2012;10(4):289-302.
8. La Rosa P, Petrillo S, Bertini ES, Piemonte F. Oxidative stress in DNA repeat expansion disorders: a focus on NRF2 signaling involvement. Biomolecules. 2020;10(5):702.
9. Obeagu EI, Bunu UO, Obeagu GU, Habimana JB. Antioxidants in the management of sickle cell anaemia: an area to be exploited for the wellbeing of the patients. International Research in Medical and Health Sciences. 2023;6(4):12-17.
10. Obeagu EI, Ogunnaya FU, Obeagu GU, Ndidi AC. Sickle cell anaemia: a gestational enigma. European Journal of Biomedical and Pharmaceutical Sciences. 2023;10((9): 72-75
11. Obeagu EI. An update on micro RNA in sickle cell disease. Int J Adv Res Biol Sci. 2018; 5:157-8.
12. Obeagu EI, Babar Q. Covid-19 and Sickle Cell Anemia: Susceptibility and Severity. J. Clinical and Laboratory Research. 2021;3(5):2768-2487.
13. Obeagu EI. Depression in Sickle Cell Anemia: An Overlooked Battle. Int. J. Curr. Res. Chem. Pharm. Sci. 2023;10(10):41-.
14. Renoux C, Joly P, Faes C, Mury P, Eglenen B, Turkay M, Yavas G, Yalcin O, Bertrand Y, Garnier N, Cuzzubbo D. Association between oxidative stress, genetic factors, and clinical severity in children with sickle cell anemia. The Journal of pediatrics. 2018; 195:228-235.
15. Gueye Tall F, Martin C, Ndour EH, Faes C, Deme Ly I, Pialoux V, Connes P, Gueye PM, Ndiaye Diallo R, Renoux C, Diagne I. Influence of oxidative stress biomarkers and genetic polymorphisms on the clinical severity of hydroxyurea-free senegalese children with sickle cell anemia. Antioxidants. 2020;9(9):863.
16. Juan CA, Pérez de la Lastra JM, Plou FJ, Pérez-Lebeña E. The chemistry of reactive oxygen species (ROS) revisited: outlining their role in biological macromolecules (DNA, lipids and proteins) and induced pathologies. International journal of molecular sciences. 2021;22(9):4642.
17. Obeagu EI, Obeagu GU. Evaluation of Hematological Parameters of Sickle Cell Anemia Patients with Osteomyelitis in A Tertiary Hospital in Enugu, Nigeria. Journal of Clinical and Laboratory Research.2023;6(1):2768-0487.
18. Obeagu EI, Dahir FS, Francisca U, Vandu C, Obeagu GU. Hyperthyroidism in sickle cell anaemia. Int. J. Adv. Res. Biol. Sci. 2023;10(3):81-89.
19. Swem CA, Ukaejiofo EO, Obeagu EI, Eluke B. Expression of micro RNA 144 in sickle cell disease. Int. J. Curr. Res. Med. Sci. 2018;4(3):26-32.
20. Obeagu EI. Sickle cell anaemia: Historical perspective, Pathophysiology and Clinical manifestations. Int. J. Curr. Res. Chem. Pharm. Sci. 2018;5(11):13-15.
21. Obeagu EI, Obeagu GU. Sickle Cell Anaemia in Pregnancy: A Review. International Research in Medical and Health Sciences. 2023 Jun 10;6(2):10-13.
22. Silva M, Faustino P. From stress to sick (le) and back again–oxidative/antioxidant mechanisms, genetic modulation, and cerebrovascular disease in children with sickle cell anemia. Antioxidants. 2023;12(11):1977.
23. Deng M, Sun J, Peng L, Huang Y, Jiang W, Wu S, Zhou L, Chung SK, Cheng X. Scutellarin acts on the AR-NOX axis to remediate oxidative stress injury in a mouse model of cerebral ischemia/reperfusion injury. Phytomedicine. 2022; 103:154214.
24. Obeagu EI, Mohamod AH. An update on Iron deficiency anaemia among children with congenital heart disease. Int. J. Curr. Res. Chem. Pharm. Sci. 2023;10(4):45-48.
25. Edward U, Osuorji VC, Nnodim J, Obeagu EI. Evaluationof Trace Elements in Sickle Cell Anaemia Patients Attending Imo State Specialist Hospital, Owerri. Madonna University journal of Medicine and Health

Sciences ISSN: 2814-3035. 2022 Mar 4;2(1):218-234.
26. Umar MI, Aliyu F, Abdullahi MI, Aliyu MN, Isyaku I, Aisha BB, Sadiq RU, Shariff MI, Obeagu EI. Assessment Of Factors Precipitating Sickle Cell Crises Among Under 5-Years Children Attending Sickle Cell Clinic Of Murtala Muhammad Specialist Hospital, Kano. blood.;11:16.
27. Obeagu EI. Vaso-occlusion and adhesion molecules in sickle cells disease. Int J Curr Res Med Sci. 2018;4(11):33-35.
28. Liu Z, Zhou T, Ziegler AC, Dimitrion P, Zuo L. Oxidative stress in neurodegenerative diseases: from molecular mechanisms to clinical applications. Oxidative medicine and cellular longevity. 2017;2017(1):2525967.
29. Ifeanyi OE, Stella EI, Favour AA. Antioxidants In The Management of Sickle Cell Anaemia. Int J Hematol Blood Disord (Internet) 2018 (cited 2021 Mar 4); 3. Available from: https://symbiosisonlinepublishing. com/hematology/hema tology25. php. 2018 Sep.
30. Buhari HA, Ahmad AS, Obeagu EI. Current Advances in the Diagnosis and Treatment of Sickle Cell Anaemia. APPLIED SCIENCES (NIJBAS). 2023;4(1).
31. Nnodim J, Uche U, Ifeoma U, Chidozie N, Ifeanyi O, Oluchi AA. Hepcidin and erythropoietin level in sickle cell disease. British Journal of Medicine and Medical Research. 2015;8(3):261-5.
32. Obeagu EI. BURDEN OF CHRONIC OSTEOMYLITIS: REVIEW OF ASSOCIATIED FACTORS. Madonna University journal of Medicine and Health Sciences. 2023;3(1):1-6.
33. Obeagu EI, Obeagu GU. Oxidative Damage and Vascular Complications in Sickle Cell Anemia: A Review. Elite Journal of Haematology. 2024;2(3):58-66.
34. Gueye Tall F, Martin C, Ndour EH, Faes C, Deme Ly I, Pialoux V, Connes P, Gueye PM, Ndiaye Diallo R, Renoux C, Diagne I. Influence of oxidative stress biomarkers and genetic polymorphisms on the clinical severity of hydroxyurea-free senegalese children with sickle cell anemia. Antioxidants. 2020;9(9):863.
35. Silva DG, Junior EB, de Souza Torres L, Júnior OR, de Castro Lobo C, Bonini-Domingos CR, De Almeida EA. Relationship between oxidative stress, glutathione S-transferase polymorphisms and hydroxyurea treatment in sickle cell anemia. Blood Cells, Molecules, and Diseases. 2011;47(1):23-28.
36. Consoli V, Sorrenti V, Grosso S, Vanella L. Heme oxygenase-1 signaling and redox homeostasis in physiopathological conditions. Biomolecules. 2021;11(4):589.
37. Aloh GS, Obeagu EI, Okoroiwu IL, Odo CE, Chibunna OM, Kanu SN, Elemchukwu Q, Okpara KE, Ugwu GU. Antioxidant-Mediated Heinz Bodies Levels of Sickle Erythrocytes under Drug-Induced Oxidative Stress. European Journal of Biomedical and Pharmaceutical sciences. 2015;2(1):502-507.
38. Obeagu EI, Obeagu GU. Sickle Cell Anaemia in Pregnancy: A Review. International Research in Medical and Health Sciences. 2023; 6 (2): 10-13.
39. Obeagu EI, Ogbuabor BN, Ikechukwu OA, Chude CN. Haematological parameters among sickle cell anemia patients' state and haemoglobin genotype AA individuals at Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. International Journal of Current Microbiology and Applied Sciences. 2014;3(3):1000-1005.
40. Ifeanyi OE, Nwakaego OB, Angela IO, Nwakaego CC. Haematological parameters among sickle cell anaemia... Emmanuel Ifeanyi1, et al. pdf• Obeagu. Int. J. Curr. Microbiol. App. Sci. 2014;3(3):1000-1005.
41. Obeagu EI, Opoku D, Obeagu GU. Burden of nutritional anaemia in Africa: A Review. Int. J. Adv. Res. Biol. Sci. 2023;10(2):160-163.
42. Ifeanyi E. Erythropoietin (Epo) Level in Sickle Cell Anaemia (HbSS) With Falciparum Malaria Infection in University Health Services, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. PARIPEX - INDIAN JOURNAL OF RESEARCH, 2015; 4(6): 258-259
43. Ifeanyi OE, Nwakaego OB, Angela IO, Nwakaego CC. Haematological parameters

among sickle cell anaemia patients in steady state and haemoglobin genotype AA individuals at Michael Okpara, University of Agriculture, Umudike, Abia State, Nigeria. Int. J. Curr. Microbiol. App. Sci. 2014;3(3):1000-1005.
44. Ifeanyi OE, Stanley MC, Nwakaego OB. Comparative analysis of some haematological parameters in sickle cell patients in steady and crisis state at michaelokpara University of agriculture, Umudike, Abia state, Nigeria. Int. J. Curr. Microbiol. App. Sci. 2014;3(3):1046-1050.
45. Ifeanyi EO, Uzoma GO. Malaria and The Sickle Cell Trait: Conferring Selective Protective Advantage to Malaria. J Clin Med Res. 2020; 2:1-4.
46. Obeagu EI, Obeagu GU. Oxidative Damage and Vascular Complications in Sickle Cell Anemia: A Review. Elite Journal of Haematology, 2024; 2 (3).:58-66.
47. Obeagu EI, Obeagu GU. Addressing Myths and Stigmas: Breaking Barriers in Adolescent Sickle Cell Disease Education. Elite Journal of Health Science. 2024;2(2):7-15.
48. Obeagu EI, Obeagu GU. Implications of climatic change on sickle cell anemia: A review. Medicine. 2024 Feb 9;103(6):e37127.
49. Singh P, O'Toole TE, Conklin DJ, Hill BG, Haberzettl P. Endothelial progenitor cells as critical mediators of environmental air pollution-induced cardiovascular toxicity. American Journal of Physiology-Heart and Circulatory Physiology. 2021;320(4):H1440-55.
50. Al-Naama LM, Hassan MA, Mehdi JK. Association of erythrocytes antioxidant enzymes and their cofactors with markers of oxidative stress in patients with sickle cell anemia. Qatar medical journal. 2015;2015(2):14.
51. Obeagu EI. Chromium VI: A Silent Aggressor in Sickle Cell Anemia Pathophysiology. Elite Journal of Haematology, 2024; 2 (3).:81-95.
52. Obeagu EI. Maximizing longevity: erythropoietin's impact on sickle cell anemia survival rates. Annals of Medicine and Surgery. 2024:10-97.
53. Obeagu EI, Ubosi NI, Obeagu GU, Egba SI, Bluth MH. Understanding apoptosis in sickle cell anemia patients: Mechanisms and implications. Medicine. 2024;103(2):e36898.
54. Obeagu EI, Ayogu EE, Anyanwu CN, Obeagu GU. Drug-Drug Interactions in the Management of Coexisting Sickle Cell Anemia and Diabetes. Elite Journal of Health Science. 2024;2(2):1-9.
55. Obeagu EI, Obeagu GU. Dual Management: Diabetes and Sickle Cell Anemia in Patient Care. Elite Journal of Medicine. 2024;2(1):47-56.
56. Wood KC, Hsu LL, Gladwin MT. Sickle cell disease vasculopathy: a state of nitric oxide resistance. Free radical biology and medicine. 2008;44(8):1506-1528.
57. Tewari S, Brousse V, Piel FB, Menzel S, Rees DC. Environmental determinants of severity in sickle cell disease. Haematologica. 2015;100(9):1108.

Access this Article in Online

Website: www.ijcrcps.com

Subject: Haematology

Quick Response Code

DOI: 10.22192/ijcrcps.2024.11.08.005

How to cite this article:
Emmanuel Ifeanyi Obeagu. (2024). Role of Autophagy in Modulating Oxidative Stress in Sickle Cell Disease: A Narrative Review. Int. J. Curr. Res. Chem. Pharm. Sci. 11(8): 38-46.
DOI: http://dx.doi.org/10.22192/ijcrcps.2024.11.08.005

