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RESEARCH ARTICLE

THE ROLE OF ISLAMIC MEDICINE IN THE 13TH-CENTURY HISTORIC DISCOVERY OF THE CORRECT FUNCTION OF THE CARDIOVASCULAR PULMONARY CIRCUIT

***,[1,2]Abdelhadi Halawa**

[1]High-End Foreign Expert and Lead Researcher, Center for Yellow River Civilization and Sustainable Development, Henan University, Kaifeng, Henan Province, China
[2]Department of Wellness and Sport Sciences, Millersville University, Millersville, PA, USA

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ABSTRACT

Introduction: For centuries, a myriad of studies and theories have been developed and arguments on both sides have been long debated regarding the early discovery of the pulmonary blood circulation. Attributions for the original discovery of this landmark medical discovery were mostly bestowed upon a number of European scholars and physicians for their individual contributions in the 15th to 17th centuries AD. Chiefly among those European contributors are Claudius Galen; William Harvey; Michael Servetus; Andreas Vesalius; and Matteo Realdo Colombo. For over 800 years, with the only exception of Galen, most of the credit for this milestone physiological discovery was given to the aforementioned European scholars and physicians; however, none was given to the 13th century AD physician Ibn al-Nafis whose contribution to this discovery is seminal and well-documented.
Purpose: This study is amid to examine the evolution of the discovery of the lesser blood circulation, the contradictory theories concerning the original discovery, as well the credit given to the early discovers of the pulmonary blood circulation spanning from the 2nd to the 17th centuries AD.
Methods: This study employed a meta-analysis systematic review methodology of a multitude of germane studies. Data obtained from these studies were analyzed in order to determine common underlying findings, arguments, and disagreements regarding the discovery of the pulmonary blood circulation.
Conclusion: Several early European physicians and anatomists, in some measures, contributed to the discovery of the functions of the lesser blood circulation. However, a well-documented body of evidence showed that Ibn al-Nafis made a pioneering contribution to the discovery, correct functions, and development of a body of invaluable knowledge in the field of cardiac anatomy and medicine.

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INTRODUCTION

Since its inception in 610 AD, Islam encouraged learning and emphasized the importance of seeking knowledge. Islam considers seeking knowledge as a religious duty required by every Muslim, female and male alike. The most important goal of seeking knowledge in Islam is to learn in order to become a better human being who can be a productive and contributing member of society.

***Corresponding author: [1,2]Abdelhadi Halawa,**
[1]High-End Foreign Expert and Lead Researcher, Center for Yellow River Civilization and Sustainable Development, Henan University, Kaifeng, Henan Province, China.
[2]Department of Wellness and Sport Sciences, Millersville University, Millersville, PA, USA.

The Prophet Mohammed instructed all Muslims to seek knowledge through all means available to them, even if they have to go as far away as China to acquire this knowledge (Sodiq, 2010). Early Muslims took this directive from the Prophet to heart and eagerly began seeking knowledge and exploration from all available sources at the time. The period of (800-1000 AD) witnessed the Renaissance of Islamic science and medicine, which made significant contributions to both the Eastern and Western civilizations. During this period, Islamic scholars, scientists, and philosophers translated numerous manuscripts written by their Greek, Persian, and Indian counterparts. They investigated these manuscripts scholarly, and contributed to broaden and advance the inquiry of science, medicine, philosophy, and mathematics. During the Scientific Revolution in Europe in the 14th–17th centuries, the Europeans

drew upon those innovations and contributions made by the Muslim physicians and scientists, including in the fields of medicine, astronomy, biology, mathematics, physics, human anatomy, and chemistry (Rosenthal, 1970 and Islamic Scientific Contributions to Civilization, 2014). During the period of (800-1450 AD) Muslim physicians and scholars contributed to establishing the foundation for medical science and practice in Europe. Prior to the emergence of Islamic medicine, medical care and practice in Europe was mainly provided by theologians and priests in primitive sanatoriums and infirmaries appended to churches and temples. Muslim physicians, on the other hand, constructed major hospitals in Baghdad, Cairo, Damascus, and Cordoba, Spain. These hospital facilities also functioned as centers of medical education, research, and training. In these medical centers many of the medical care concepts and structures that have been currently practiced in modern hospitals, such as separate wards for certain critical illnesses; independent units for men and women; institutional and personal hygiene; onsite pharmacies; and maintaining medical records are modeled after those that were conceived and practiced by the early Muslims physicians and medical caretakers (Majeed, 2005).

The Mythology of the Human Heart in Ancient Civilizations

The early Greeks recognized that the heart as one of the most vital organs in the human body. In many cultures, the heart is not only a significant organ physiologically and anatomically, but also has been associated with life and death both in corporeal and metaphorical terms. In his book "The Mythology of the Heart", Nager (1993) articulated how the metaphoric and representational manifestations of the heart are expressed in religion, arts, and literature; and how they have profoundly influenced various cultures in more than one way. Ancient Egyptians believed that the human heart has a dominant role and controlling influence over a person's body not only physically, but also metaphysically and mystically.

As early as 1500 BCE, documented in medical papyrus, ancient Egyptian physicians emphasized the importance of the arterial pulse of the heart, its character, and its force in understanding the health status of a person (Table 1). Lyons and Petrucelli (1997) noted the special sacredness and symbolic significance of the heart throughout the history of civilizations. The authors described that ancient Egyptians had a particular respect for the heart. They believed that after biological death, people will need to have their hearts with them in the afterlife to reunite (enter-the-flesh-again) with a new body for the eternal life. As it was instructed in their interment rituals on the papyrus in the ancient text "The Egyptian Book of the Dead", the heart would be weighed and compared to the weight of a feather, and would be preserved in individually-designed containers resembling the shape of the dead person's actual heart to be returned to the new body after reincarnation or the transmigration of the soul. Hieroglyphic papyrus scripts known as the "Edwin Smith Surgical Papyrus" are Ancient Egyptian medical texts discovered by the American Egyptologist and collector Edwin Smith in the ancient city of Thebes (present-day Luxor) in 1862 (Figure 3). This surgical papyrus was found to be connected to Imhotep, the renowned polymath, high priest, deity, and the Pharaoh Djoser's (Arabic: زوسر) chief physician in his time of the Old Kingdom in 3000-2500 BC. The hieroglyphic scripts of this papyrus provided a description of the heart as the center of a system vessels extending to the periphery of the body. These oldest ancient medical scripts also revealed that ancient Egyptians believed that there is a direct correlation between the pulse, heart function, life, and end of life (Lyons and Petrucelli, 1997, Meyerhof, 1935, West, 1985, Wilkins, 1992 and Willerson and Teaff, 1996).

The human heart fascination was particularly evident in the Greek culture. Ancient texts and archeological discoveries showed that the Greek civilization had a deep-rooted influence on the early development of numerous medical theories and practices. Many of these theories and practices were disseminated to and adopted by other cultures. They then became a nucleus for further analysis and advancement in medical science and practice throughout the world, particularly during the development of the Greco-Islamic medicine in the course of the Islamic Golden Age (8^{th} to 14^{th} centuries AD). Despite its shortcoming, the early theory on the pulmonary blood circulation was brought to bear by the prominent Greek physician, surgeon and philosopher Claudius Galenus, better known as Galen in the 2^{nd} century BC. In his theory, Galen purported that the arterial and venous systems are totally detached from each other and only connected through unseen passages or pores located in the interventricular septum "cardiac septum" (Jones, 1932, Meyerhof, 1935 and West, 1985). Galen also suggested that the liver produced deoxygenated (dark) blood that was then transported into the right side of heart to be distributed to the left side of the heart where it amalgamates with oxygen to create a "vital spirit" and then is transported to the tissues in the entire body through the "greater" now known as the systemic blood circulation (Meyerhof, 1935, Kaf-Alghazal, 2007 and Aird, 2011).

In 12^{th} century, in his book "The Law of Medicine", Ibn Sina (Avicenna) agreed in principle with Galen's point of view; however, he also argued that the heart consisted of three chambers and not four, and that the heart received its nourishment from the right ventricle (Haddad and Khairallah, 1936 and West, 1985). Galen's concept of how the lesser blood circulation functions lasted for approximately 15 centuries until it was challenged by Ibn al-Nafis in the 13^{th} century. Galen's concept was also disputed by William Harvey when he published his book titled in Latin "De Motu Cordis", and in English "On the Motion of the Heart and Blood in Animals in 1628 BC. In his book, Harvey provided experiment-based arguments and inferential logic in order to support his theory regarding the anatomical function and interconnectedness between arterial and venous systems, which in Galen's view are completely two separate systems. Harvey also is credited with having discovered the mechanistic principles of blood circulation throughout the body, which is diametrically conflicting with Galen's theory of "elusive attractive powers" (Kaf-Alghazal, 2007, Aird, 2011 and Azizi, *et al.,* 2008). Prior to William Harvey, in the 13^{th} century, Ibn al-Nafis also had reservations regarding the correctness of Galen's assumption of the structure of the lesser blood circulation. In his diagram, he anatomically demonstrated that there are no invisible passages or pores found in the interventricular septum (septum cardis)

for the blood to flow through the heart and lungs as Galen previously postulated (Kaf-Alghazal, 2007 and Meyerhof, 1935). Subsequent to the aforementioned theories and concepts on the lesser blood circulation, as chronicled in Table 1, a number of other physicians and scholars' observations and contributions emerged in Europe by either agreeing or disagreeing with some of the earlier theories, and who in fact should be worthy of the credit for their original discovery or rediscovery of the cardiovascular circulation.

MATERIALS AND METHODS

Numerous published research papers and studies represent diverse positions on the early discovery of the functions of the human pulmonary (lesser) blood circulation were systematically reviewed and analyzed. Data obtained from the analysis of these research papers and studies were examined in order to answer the question that has motivated the current study, which was who was the first physician that discovered the correct functions of the lesser pulmonary blood circulation? In order to arrive to an answer to this question, this study employed a meta-analysis systematic review methodology of a multitude of germane published studies, as well as authoritative books on the subject under investigation. The data obtained from these research papers, studies, and books were analyzed in order to determine common underlying findings, arguments, and counterarguments regarding the early discovery of the pulmonary blood circulation.

Claudius Galenus, also known as Galen

Galen was the greatest physician of his time in ancient Rome. He was also a prominent Greek surgeon and medical philosopher. He was born around 129 AD in Pergamum, which was an old Greek city on the Aegean Sea coast of Asia Minor (present-day Turkey), which was then a prefecture of the Roman Empire. He served as the surgeon to the gladiators in Pergamum. This position afforded him extensive training and substantial knowledge and skills in the fields of anatomy and surgery. While Hippocrates is credited for establishing the foundation of ancient Greek medicine, Galen is recognized for his work expanding on a number of Hippocratic fundamental medical theories and practices that lasted for centuries such as his humoral physiology and pathology.

He also brought the Greco-Roman medicine to its apogee. Galen who died at the age of 70 was celebrated as the most prominent Greek physician and philosopher, second only to Hippocrates. As an anatomist, he dissected different kinds of animals and was able to describe the anatomical functions of various body organs, as well as two different kinds of blood. He described one type of blood that is darker carried by the veins and produced by the liver, and another type of bright blood carried by the arteries and produced within the heart itself. In Galen's interpretation, both the darker and bright bloods were distributed to the extremities of the body and only used up by the peripheral body tissues. Galen's suggestion that arteries carried blood was a major improvement from his predecessor Aristotelian's theory that arteries carried air or vital spirit and not blood. His most challenged and debated theory was his concept of the function of the lesser blood circulation.

Galen theorized that the blood flowed from the right to the left ventricle was passed directly through "invisible" pores or passages located in the interventricular septum (IVS) "septum cardis" separating the two ventricles (Figure 2). Centuries later, Galen's theory on "invisible" pores in the IVS was questioned and corrected by Ibn al-Nafis, who concluded based on his anatomical examination that there were no any invisible or hidden pores or passages found in impenetrable thick septum wall separating the two ventricles (Azizi, *et al*., 2008, Ergi, 1997, Kaf-Alghazal, 2007 and Meyerhof, 1935).

Ala'a Al-Din Al-Dimashqi, also known as Ibn Al-Nafis

Ibn al-Nafis (1210-1288 AD), was a Muslim Syrian physician and scholar who made major contributions to the advancement of medical knowledge and science in the 13th century AD. His involvement in several fields of science, such as anatomical, physiological, jurisprudence, and political studies made him a noteworthy contributor to these fields of inquiry (Al-Dabbagh, 1978 and Loukas, *et al.,* 2008). As a physician, one of the most significant achievements of Ibn al-Nafis was his discovery of the correct function of the pulmonary circulation, also referred to as the "lesser blood circulation". He re-examined the question of the correct mechanism of blood circulation in the human body. He also provided a detailed description of the correct anatomy of the lungs and bronchi, as well as the interface between the vascular system, extraction of air, and gas exchange in the alveoli. The 2nd century AD concept of how the pulmonary circulation works was attributed to the work of the Greek physician Galen (129-201 AD), which had existed with no change or challenge for more than 1000 years.

Based upon his knowledge in human anatomy and scientific reasoning, Ibn al-Nafis disagreed with Galen and challenged his ingrained scientific rationale and depiction of how the human pulmonary circulation actually carries blood from one side of the heart to the other (Haddad and Khairallah, 1936, Meyerhof, 1935 and Masic, 2010). There was an unanswered question of how blood flows from the right ventricle of the heart to the left ventricle before the blood is pumped to the rest of the body through the greater (systemic) circulation without the existence of detectable apertures (manafiz "ذفـــانم" in Arabic). According to Galen's postulation, when blood enters the right side of the heart it has to go first through some invisible passages or pores in the cardiac septum (septum cardis), and then it goes to the left side of the heart to be mixed with oxygenated blood (vital spirit), and is then transported to the rest of body via the greater (systemic) blood circulation (Hehmeyer and Khan, 2007, Rafiabadi, 2005 and Akmal, *et al.,* 2010).

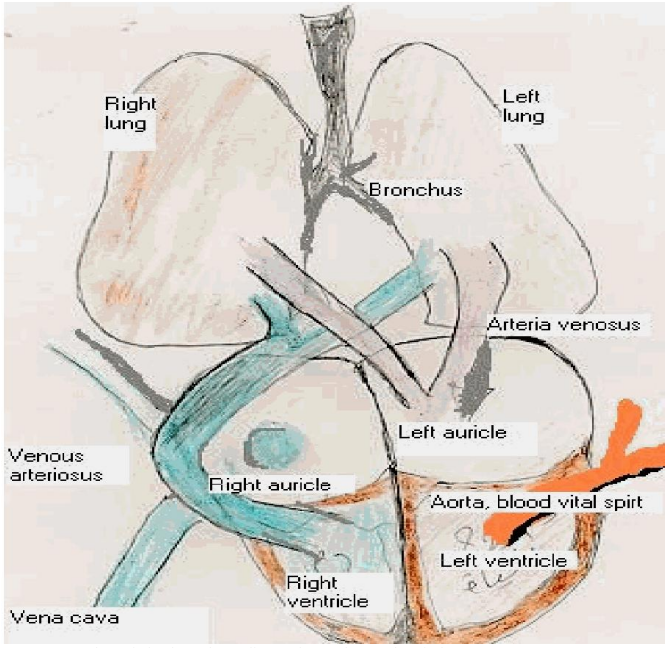
Through the means of his observations and anatomical analysis of the mechanics of the lesser blood circulation, Ibn al-Nafis concluded that the explanation by Galen of how blood flows from the right chamber to the left chamber through the unseen pores in the thick-walled cardiac septum to be erroneous (Hehmeyer and Khan, 2007, Akmal, *et al.,* 2010 and Meyerhof, 1935). Ibn al-Nafis discovered that the thick interventricular septum was not porous and it is impassable for the blood to stream through it, because he found that it is lacking any types of invisible passages or pores as Galen claimed.

With his new findings, Ibn al-Nafis was able to establish that Galen's hypothesis to be anatomically and logically unsupported by clinical facts (Hehmeyer and Khan, 2007, Meyerhof, 1935 and Masic, 2010). Based on his clinical investigation, Ibn al-Nafis discovered that the blood coming from the right chamber of the heart must first arrive to the left chamber but there is no direct pathways or pores between them. He also discovered that the thick septum of the heart is not perforated and does not have any invisible passages as Galen initially thought. Furthermore, Ibn al-Nafis maintained that the blood from the right chamber of the heart must flow through the pulmonary artery to the lungs to be mixed there with oxygen (vital spirit); then it passes through the pulmonary vein to reach the left chamber of the heart and goes from there to the rest of the body through the greater (systemic) blood circulation (Hehmeyer and Khan, 2007, Hamarneh, 1972, Rafiabadi, 2005, Meyerhof, 1935 and Akmal, *et al.,* 2010). His discovery was one of the first accurate and evidence-based descriptions of the human pulmonary circulation (Hehmeyer and Khan, 2007 and Rafiabadi, 2005).

It was not until 1924 that an Egyptian physician named "Muhyo Al-Deen Al-Tatawi" uncovered a rare and long-forgotten historical document written in Arabic titled "Commentary on the Anatomy of Canon of Avicenna" in the Prussian State Library in Berlin, Germany. This original manuscript authenticated that the early discovery of the lesser blood circulation was, in fact, attributable to the work of Ibn al-Nafis in the 13th century AD. This document covers, in greater detail, the work done on the anatomy, pathology, and physiology of the role of the heart and lungs in the pulmonary blood circulation by Ibn al-Nafis (Haddad and Khairallah, 1936) (Figure 1). Historically, this was the earliest original documented description found on the functions of the pulmonary circulation (Haddad and Khairallah, 1936 and Meyerhof, 1935). However, it was because of William Harvey's (1578–1657 AD) independent research on the subject that led to bringing the pulmonary circulation document into a broader public attention, as well as subsequent further examination and debate by physicians, scientists, and historians (Hannam, 2011 and Meyerhof, 1935).

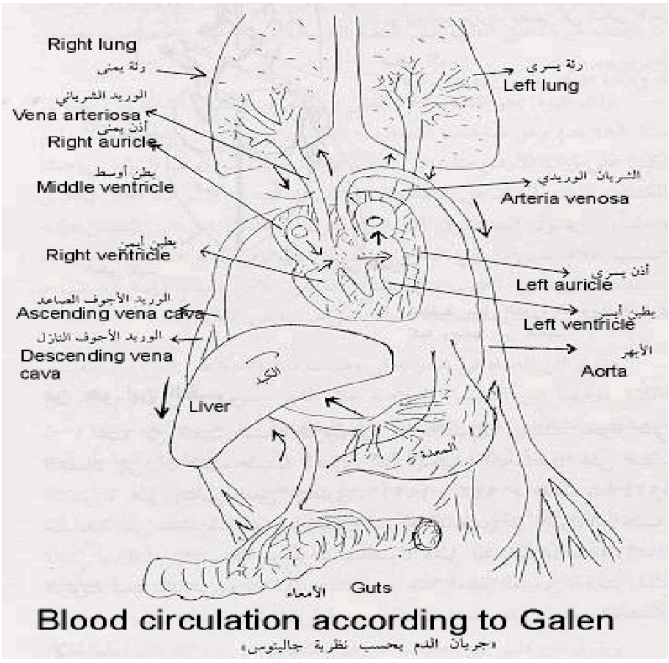
Due to Ibn al-Nafis' documented discovery, there is a recognition in the scientific community of the inaccuracy in the historical allegations that the pulmonary circulation was discovered by European medical scientists during the 16th century AD. As a result of this discovered document by Al-Tatawi, there is a convincing assumption in the medical community that those European scientists must have had a possession of or access to the translated manuscript of Ibn al-Nafis' blood circulation discovery. In 1547, Andrea Alpago, was an Italian physician who translated from Arabic into Latin Ibn al-Nafis' manuscript. Alpago who lived in Damascus, Syria and worked as a physician for nearly 30 years was erudite in several languages, including Arabic. Because of his translation, the work of Ibn al-Nafis was available in Latin in Europe in the mid-15th century AD (Coppola, 1957, Keys and Wakim, 1953 and Qatayyah, 1984). In the mid-1930s, the German physician, Max Meyerhof published German, French, and English translations of selected pertinent excerpts of the observations made by Ibn al-Nafis.

One of these translations included a reproduction of the Arabic text of Ibn al-Nafis' work on the lesser blood circulation (Figures 4 and 5) (West, 185 and Meyerhof, 1935). In 1947, Mettler accredited Ibn al-Nafis for the fact that he was able to discover the existence of a porous system of blood vessels in a capillary network that makes the passage of air into pulmonary circulation possible. He was able to accomplish this significant clinical discovery even though at this time in the 13th century, there were no microscopes available in medical research. To honor Ibn al-Nafis for this work, the author termed this system "the Nafisian System" (Mettler and Mettler, 1947).



Source: Al-Hajaj, Ibn al-Nafis and Modern Physiology.

Figure 1. Ibn al-Naris's Depiction of Blood Circulation



Source: Al-Hajaj, Ibn al-Nafis and Modern Physiology.

Figure 2. Galen's Depiction of Blood Circulation

Source: http://www.crystalinks.com/egyptmedicine.html.

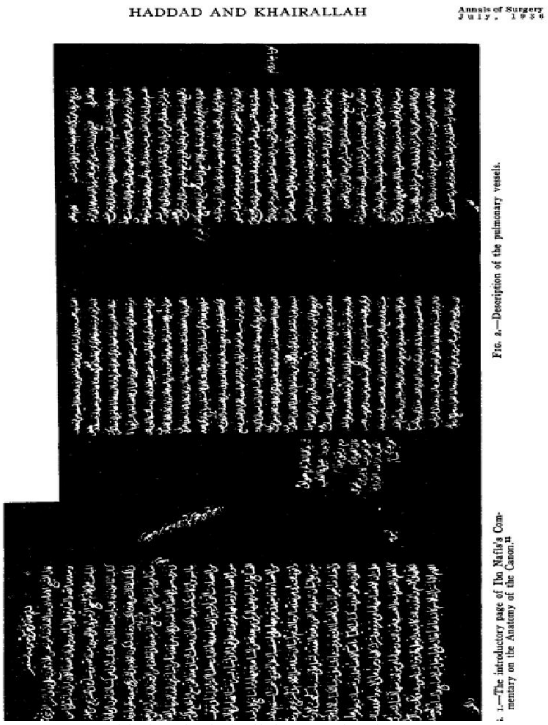
Figure 3. The Edwin Smith Surgical Papyrus

William Harvey

Harvey (1578-1657 AD), was a prominent English physician and biologist. He was born in Kent County in South East England and studied medicine at Cambridge University. He also was medically trained at the Italian University of Padua, which was the most prestigious medical university at the time, where Andreas Vesalius and Realdo Colombo studied medicine as well (Zampieri, *et al.,* 2013). He set up a successful medical practice in London and is credited with having contributed to the discovery of the basic mechanics of how the human blood circulation works. He also described the properties of the blood pumped by the heart and circulated through the vascular system to the brain and other parts of the body. Harvey was trained in practicing medicine under the patronage of the renowned Italian anatomist and embryologist "Hieronymus Fabricius", where Harvey became influenced by his medical concepts and techniques. At the time, Fabricius had previously published his work on the discovery of the semi-lunar valve of a vein. He theorized that these one-way valves can only allow the blood to flow in the direction of the heart.

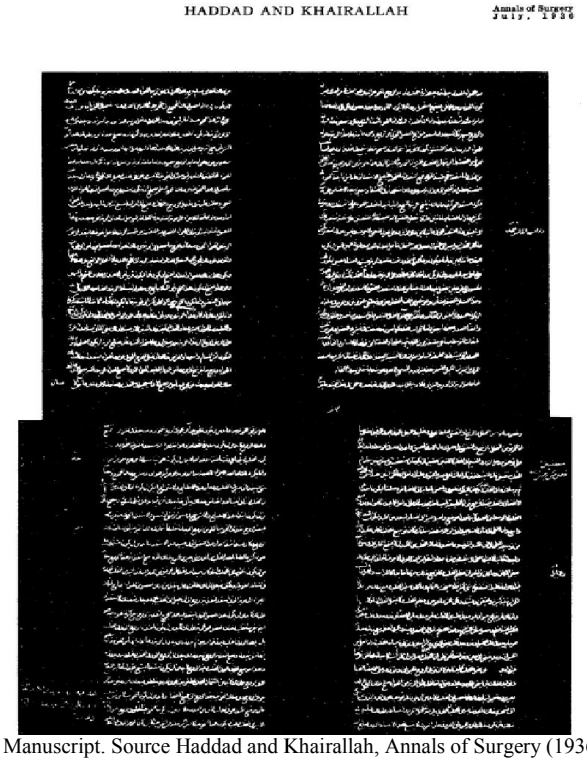
In 1628, Harvey published his classic book titled in Latin "Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus", and in English as "On the Motion of the Heart and Blood in Animals". In his book, Harvey explained that in his experiments, he applied observational deduction and reasoning to demonstrate that veins and arteries are anatomically and operationally interconnected to the lungs and the peripheral tissues. He also suggested that the blood circulates through these veins and arteries ad infinitum. In the course of dissecting numerous animals and employing the quantitative approach of research, he concluded that to the amount of blood that can be ejected by the heart in a unit of time and the total amount of blood that can be contained by the heart and blood vessels at any one time.

He came to the conclusion that the same amount of blood must be circulating throughout the body, and it must return with oxygen-rich blood back to the heart. Harvey also established a theory on "the mechanical force of the heart", which negated Galen's earlier "elusive attractive powers" theory. With his evidence-based work on the cardiovascular system, Harvey was able to show that the Galenic physiological concepts of blood circulation were incorrect and lacked experimentally-supported evidence. Harvey's work was denounced, particularly by the French physician and Galen's medical theory supporter "Jean Riolan" in his book titled "Opuscula Nova Anatomica*"* in 1649 AD. In response to this denunciation, Harvey was compelled to defend his work in his book "Exercitatio anatomica de circulations sanguinis", which was also published in 1649 AD, where Harvey argued that Riolan's position was conflicting with all investigational evidence and lacks any scientific reasoning.



Source: Haddad and Khairallah, Annals of Surgery (1936).

Figure 4. Introductory Page of Ibn al-Nafis' Arabic Manuscript



Manuscript. Source Haddad and Khairallah, Annals of Surgery (1936)

Figure 5. Description of the Anatomy of the Lungs and Heart of Ibn al-Nafis' Arabic

Despite of the attack on his work, Harvey was still regarded as a highly accomplished physician. Eventually, Harvey's substantial evidence brought forth a new body of physiological knowledge on the heart and blood circulation that prevailed since the 16th century AD (Aird, 2011, Azizi, *et al.,* 2008 omson, 2014).

Michael Serventus

His Spanish name is Miguel Serveto Conesa (1509-1553 AD), and he was a Renaissance era French physician of Spanish descent. He was also a theologian and cartographer who hailed from a noble Spanish devout Christian family. Servetus was put on trial and condemned by the Geneva Council "to be led to Chample (a small district on the outskirts of Geneva, Switzerland) and burned alive together with his books", including the book he wrote on the minor blood circulation. His execution by immolation was a retribution for his writing on his Unitarian religious beliefs, as well as his disagreement with the Holy Trinity doctrine. He was sentenced to death by setting him ablaze at the stake in Geneva, Switzerland in 1553 AD (Goldstone and Goldstone, 2002).

While some European writers and supports claimed that Servetus was the first physician yet to openly question Galen's original concept, and that he also was the first discoverer of the respiratory blood circulation (he referred to it as the small circulation), other researchers are more skeptical of those claims. According to Stefanadis *et al*. (2009), there is still a great deal of difference of opinions among historians as to whether Servetus was in fact the first physician who discovered the pulmonary circulation, or whether this historic distinction should be awarded to another more worthy physician. Most British medical historians who endorsed the notion that William Harvey was the inventor of the pulmonary circulation argued that Servetus might have rediscovered the already discovered blood circulation. This "rediscovery theory" by Servetus was not all the more so widely and scientifically accepted, nor was supported by documents, since most of Servetus' books and treatises that he authored about this subject and others were set aflame with him in the Swiss locality of Chample nearby Geneva in 1553 (Stefanadis *et al.,* 2009).

Thus far, based upon the aforementioned, three facts have been established. First, William Harvey's discovery post-dated the discovery of Ibn al-Nafis by at least 300 years. Second, it seems reasonably failsafe to conclude that Harvey had an access to, or even came into his possession the translated version of the manuscripts of Ibn al-Nafis' work on the lesser blood circulation, which had enabled him to build on and advance his own theories on the blood circulation, veins, and arteries. The third fact presented in this paper is that the claims that Michael Servetus was the first physician to discover the small blood circulation have been strongly refuted by a wide spectrum of the British medical historians, as well as the fact that these claims were not substantiated by any documents or records since the greater number of his books were scorched with him when he was doomed to death, as has been described earlier in this paper.

Logically, based on this comparative analysis of all the claims and counterclaims, the most convincing evidence leads us to believe that Ibn al-Nafis's work on the discovery of the pulmonary circulation came into existence in the 13th century, which places him ahead in the lead further than any of his successors by at least three centuries. All of the claimed works on the blood circulation that were carried out by others such Colombo, Harvey, and Servetus ensued that of Ibn al-Nafis', and can be considered as rediscoveries or replications of the pioneering work on the subject accomplished by Ibn al-Nafis.

Realdo Colombo

Another controversy concerning the original discovery of the respiratory blood circulation relates to yet another claim that Matteo Realdo Colombo (1510-1559 AD) was the first physician who actually discovered that exceedingly disputed cardiovascular circulation. Colombo was an Italian surgeon and anatomist whose most known work in medical research was based on his observations gleaned from dissecting of human cadavers and live animals. He studied medicine at the University of Padua in Italy, where Andreas Vesalius and William Harvey also received their training as physicians [(35)]. Based on his medical research, Colombo described the general function of the heart, where he provided an accurate account of how blood flows into the lower chambers of the heart during the diastolic movement, as well as the relaxation of the heart muscle and pumping blood out during the systolic contraction of the heart. In terms of his work on the minor blood circulation, Colombo sketched out the circulation of the deoxygenated venous blood (dark blood) from the right ventricle of the heart through the pulmonary artery to the lungs, where it turns into bright red after mingling with air "spirit energy", and then it flows into the left ventricle through the pulmonary vein, which was then known as the greater (systemic) blood circulation (Matteo, 2015).

Founded on his examination Colombo's work, Jones (1932) concluded that Colombo was most remembered by his great skill and experience in autopsy, dissection, and vivisection of living animals. Jones also added, in his only published book, the "De Re Anatomica", which was published posthumously in 1559, Colombo provided a precise description of the eye, the pleura, and the peritoneum. According to Jones, his best work was his discovery of the course of the movement of blood from the right cardiac ventricular to the left one through the lungs (the pulmonary circuit Jones, 1932). It is not quite clear whether the work on the role of the arterial and ventricular cavities in pulmonary circuit by Colombo was affected by, or replicated from the earlier discoveries made by his forerunners such as Ibn-al-Nafis and Servetus. Stefanadis, *et al.* (2009) argued that Colombo's work was interrelated or influenced by that of Servetus'. The Authors supported this argument by stating that it appears almost certain that Colombo was a contemporary of Servetus, and that he knew about Servetus' discoveries from his own observations on this subject, which was long before the posthumous publication of Colombo's book in 1559. To be precise, Colombo's book was published six years after the passing of Servetus making a strong case for the probable connection between Servetus' discovery and Colombo's work on the same subject, which was also

published in his book. Moreover, the authors corroborated their position of the apparent connection between the work of Servetus and that of Colombo by referring to one of the most enthusiastic of William Harvey's chronographers, Gweneth Whitteridge, who acknowledged that Colombo was probably aware of Servetus' anatomical discoveries and had some bearing on writing his book on the same subject. Whitteridge also stressed that if Colombo sidestepped any reference to Servetus' work as one of his bibliographic sources; it was most probably because of Colombo's trepidation of the fate that Servetus faced as a result of the Geneva Council tribunals against witchcraft and accusation of heresy known as the "Holy Inquisition", also known as "La Santa Inquisition". In addition, in his posthumously published book "De re Anatomica", Colombo, provided a detailed account of the function of the pulmonary blood circulation, Servetus' writings about the subject and those of Colombo's are remarkably similar (Stefanadis *et al.,* 2009).

DISCUSSION

In their study on the history of the discovery of the pulmonary blood circulation, Stefanadis et al. stated that "Michael Servetus was the first doctor ever to challenge and scientifically argue against the theories of Galen, which predominated for 14 centuries in medical schools worldwide." Based on the credible evidence in this paper regarding the chronology of the early discovery of the pulmonary blood circulation (Figures 1 and 2), this argument by the authors is both historically and factually incorrect. The authenticated documents discovered in a German library in 1924 by "Al-Tatawi" confirmed that Ibn al-Nafis (1210-1288 AD), was the first physician to challenge and correct Galen's theory preceding Michael Servetus (1510-1559 AD) and Realdo Colombo (1510-1559 AD) by nearly three centuries. It is logical to conclude that any work was done on the discovery of the pulmonary blood circulation that occurred after the 13th century was based upon the medical work on the lesser blood circulation by Ibn al-Nafis.

This paper has already demonstrated that in 1547, Andrea Alpago translated Ibn al-Nafis' manuscript from Arabic to Latin (Diamond, 2008) Because of his translation, the work of Ibn al-Nafis was obtainable in Latin in Europe in the mid-15th century. Furthermore, in the mid-1930s, the German physician, Max Meyerhof published German, French, and English translations of selected relevant passages of the clinical observations and written commentary made by Ibn al-Nafis. One of these published translations included a reproduction of the Arabic text of Ibn al-Nafis' work on the subject (Figures 1 and 2). Numan (2014) also questioned the claim that Harvey was the first physician that discovered the small blood circulation.

The author maintained that "Ibn al- Nafis, born 1213, was the first to discover of the "circulation lesser" and described the flow of blood from the right ventricle to the lungs through the pulmonary artery, and then it flows back with "vital spirits" to the left ventricle. More recently, in his book "1000 Events that Shaped the World", Diamond (2008) noted that the circulation of blood through the lungs was discovered in the 13th century by an "Egyptian" doctor, but his information was unknown in Europe. The reference to Ibn al-Nafis as being an "Egyptian" doctor by Diamond can be explained by the fact that in 1236, Ibn al-Nafis moved to Egypt and lived and worked there as a physician until his death in 1288. He worked at the Al-Nassri Hospital; and at a later time, worked at the Al-Mansouri Hospital, where he became chief of physicians and the Sultan's personal physician. The claim that the information regarding Ibn al-Nafis's original discovery of the circulation of blood was unknown in Europe, does not and should not abrogate the historical fact that he was the first to challenge the Galenic concept, and was able discover the correct blood circulation. In the same book, Diamond referred to Colombo as the doctor who "rediscovered" blood circulation after the execution of Servetus by burning. As has been discussed beforehand in this paper, Stefanadis *et al.* (2009) suggested that Colombo's work was replicated from that of Servetus' as it is evident in his book that he published six years subsequent to the death of Servetus. The authors also suggested that since Colombo was contemporaneous to Servetus, and that he had direct knowledge about Servetus' blood circulation discoveries from his own observations on this subject, it is almost certain that there is a clear link between Servetus' discovery and Colombo's work on the same subject.

Conclusion

A significant body of literature supported by credible historical documents points out to the fact that the lesser blood circulation was challenged, corrected, and described by Ibn al-Nafis in 1242 AD, three centuries before his European physicians succeeded him. In the landmark medical encyclopedia titled "Commentary on Anatomy in Avicenna's Canon", Ibn al-Nafis described the correct anatomy of the pulmonary circulation and provided illustrations of how the blood travels from the right side to the left side of the heart. In his commentary, he also established that blood coming from the right chamber of the heart must eventually flow to the left chamber but there are no direct visible passages between them. He discovered that the thick interventricular septum of the heart, which separates the left ventricle from the right ventricle, is not perforated and does not have some invisible pores as Galen assumed.

Based on his discovery, Ibn al-Nafis was the first anatomist to challenge Galen's 2nd century assertion at least 300 years before Servetus, Colombo, and Harvey, respectively" (Janin, 2006 and Rafiabadi, 2005). More recently, Diamond (2008) noted that the circulation of blood through the lungs was discovered in the 13th century by an "Egyptian" doctor, but his information was unknown in Europe. The reference to Ibn al-Nafis by being an "Egyptian" doctor by Diamond was due to the fact that in 1236, Ibn al-Nafis moved to Egypt and lived there until his death in 1288. He worked at the Al-Nassri Hospital; and at an afterward time, he worked at the Al-Mansouri Hospital, where he became chief of physicians and the Sultan's personal physician. The claim that the information regarding Ibn al-Nafis's original discovery of the circulation of blood was unknown in Europe, does not and should not negate the historical fact that he was the first physician to challenge Galen's hypnosis and discover the correct function of the cardiovascular circulation.

In his classic treatise on the subject, Meyerhof (1935) maintained that it was evident to him that there was no question of any circulation of the blood because Galen never mentioned in his description of the circulation of blood anything on the subject of the "reflux" of blood, that is to say the flow of blood in the opposite direction of its usual flow. He also added, Galen himself, did not seem to have formed a well-defined notion of the complete process of the circulation of blood. Galen thought that venous blood was created and continually being reproduced or restored by the liver, and then transported to the peripheral organs of the body where it is consumed. Galen's unconfirmed theory was accepted by the Hellenic, Syriac, and Muslim physicians for several centuries. After it was translated into Latin from Arabic based on Ibn Sina's (Avicenna) commentary in his book, The Canon of Medicine (Arabic: القانون في الطب — al Qānūn fī al-Ṭibb), it was also accepted by the medical community in Western Europe. Moreover, Galen's theory was not even challenged by the great Belgian physician and anatomy reformer at the time, Andreas Vesalius (1514-564 AD).

stated that, while he rejects Avicenna's argument that the heart encompasses three ventricles, as well Aristotle's rationale that the number of ventricles in a heart varied commensurable with the size of the animal itself. Ibn al-Nafis disagreed with both Avicenna and Aristotle and corrected them by stating that "these opinions are not correct; the heart has two ventricles only. One of them is filled with blood — that is the one on the right-side of the heart; and the other filled with "vital spirit", which is the one on the left-side of the heart. Ibn al-Nafis further explained that there are no passages to be found between these two ventricles; if there were, the blood would penetrate to the place of the "spirit" and would spoil its substances. Anatomy of the heart contradicts the opinions of the former essayists, as the septum between the two ventricles is of thicker substance than other parts in order to prevent the passage of blood or spirit, which might be harmful to the heart. Grounded on the above-delineated facts, history, and documents, it would be reasonable to ascertain that Ibn al-Nafis was the first physician to discover and describe the correct function of the lesser blood circulation for three persuasive

Table 1. Contributions made throughout the history to the discovery of blood circulation in chronological order

Author/Investigator	Time Period	Contributions
Egyptian physicians in medical papyrus	1500 BCE	Proposed the importance of the arterial pulse, its character, and its force in understanding health.
Hippocrates	460–370 BCE	A clear description of the ventricles, the vessels (recognizing the difference between arteries and veins), and the semilunar valves is found in his writings.
Aristotle	384–322 BCE	Described that the heart was central, mobile, and well supplied with structures that served to communicate between it and the rest of the body.
Erasistratus	304–250 BCE	Air, attracted by the lungs, passed into the pulmonary veins, from there into the left ventricle, and from the left ventricle it passed into the arteries, which distributed it to all parts of the body.
Claudius Galen	129–217 CE	Stated that the arteries contain blood, not air.
Ibn al-Nafis	1213–1288	Stated that the interventricular septum is not porous and proposed the existence of the pulmonary circulation.
Leonardo da Vinci	1452–1518	He established through experiments that air doesn't enter heart from lungs. He also proved conclusively that the valves allowed the blood to pass in only one direction and prevented its regurgitation.
Andreas Vesalius	1514–1564	Observed that the interventricular septum is not perforated.
Michael Servetus	1511–1553	Described the pulmonary circulation.
Realdus Columbus	1515–1559	He independently discovered the pulmonary circulation. He also discovered that the heart's four valves permitted the flow of blood in only one direction.
Andreas Caesalpinus	1524–1603	Described the passage of the blood from the right heart through the lungs to the left heart and used the term "circulation" to describe this process.
Hieronymus Fabricius	1537–1619	He discovered the valves in the veins. He noticed that the blood cannot move from the heart toward the periphery through the veins.
William Harvey	1578–1657	Explained the complete process of circulation.
Marcello Malpighi	1628–1694	He established the presence of capillaries with the help of a microscope. He proposed that capillaries are the connections between arteries and veins that allow blood to flow back to the heart, thus completing the gap in the knowledge of circulation.

Source: Patwardhan, Advances in Physiology Education Published, American Physiological Society (2012).

It was not up until the 13th century that Ibn al-Nafis questioned and corrected both Galen's unconfirmed theory and Ibn Sina's consequent observations on the workings of the pulmonary blood circuit, especially the concept of the existence of invisible pores or perforations in the thick-walled interventricular cardiac septum from the right vertical through the left one. As reported by Meyerhof (1935), Ibn al-Nafis

reasons: the first, he was the first to challenge and factually correct his predecessors Galen, Aristotle, and Avicenna on the anatomy of the heart and function of the pulmonary blood circulation; the second, he was the first anatomist to correctly to describe the composition of the lungs and provided an accurate explanation of the bronchi and their interface between the vascular system and the body; the third, he preceded and

predated all of his successors, including Servetus; Colombo; and Harvey by at minimum 300 years. The claims that have been made that those exclusively 15th and 16th centuries European physicians and anatomist were the first ever to discover the lesser pulmonary circulation have no support by historical facts, objective rationale, or documentations. By no means, this conclusion is to deny or refute their and other medical scholars' valuable contributions (Table 1) to the subject, especially the contributions made by William Harvey whose work enhanced the understanding of the functions of both the lesser and greater blood circulations. Every one of the above-mentioned physicians and anatomists was inventive in his domain of research, and each one of them, in some measures, contributed to the advancement of medical research and left behind a patrimony of knowledge for others to build on. It is also noteworthy to point out that based on a well-documented body of evidence that Ibn al-Nafis made a pioneering invaluable contribution to the discovery, development, and advancement of a body of knowledge in the field of cardiac anatomy and medicine.

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REFERENCES

Aird, W. C. 2011. Discovery of the Cardiovascular System: From Galen to William Harvey. *Journal of Thrombosis and Haemostasis,* Vol. 9 (suppl. 1), pp. 118–129.

Al-Dabbagh, S. A. 1978. Ibn Al-Nafis and the Pulmonary Circulation. *The Lancet,* Vol. 311, Issue 8074, pp.1148-1149.

Al-Hajaj, M. 1987. Diagram of Blood Circulation According Ibn al-Nafis. Ibn al-Nafis and Modern Physiology, Proceedings of Symposium on al- Soufi and Ibn al-Nafis, Amman, Jordan, (6), p.132. Akmal, M., Zulkifle, M. and Ansari, A. H. 2010. Ibn Nafis - A Forgotten Genius in the Discovery of Pulmonary Blood Circulation. Heart Views, Vol. 11 (1): pp. 26-30.

Al-Hajaj, M. 1987. Diagram of Blood Circulation According to Galen's Teachings. Ibn al- Nafis and Modern Physiology, Proceedings of Symposium on al-Soufi and Ibn al-Nafis, Amman, Jordan, (6), p.131.

Azizi, M. H., Nayernouri, T. and Azizi, F. 2008. A Brief History of the Discovery of the Circulation of Blood in the Human Body Arch. Iranian Med., Vol. 11 (3): pp. 348-349.

Coppola, E. D. 1957. The Discovery of the Pulmonary Circulation: A New Approach. *Bull. Hist. Med.,* Vol. 31, pp. 44-77.

Diamond, J. 2008. 1000 Events that Shaped the World: History Series. National Geographic Books, Illustrated Ed., ISBN 9781426203145, p. 134.

Ergi, K. V. 1997. Ancient Healing: Unlocking the Mysteries of Health and Healing Through the Ages, Publications International Ltd., ISBN10: 0785324313, pp. 68-95.

Goldstone, L. and Goldstone, N. 2002. Out of the Flames: The Remarkable Story of Fearless Scholar, a Fatal Heresy, and One of the Rarest Books in the World, Random House, ISBN 0- 7679-0837-6, p. 2.

Haddad, S. E. and Khairallah, A. A. 1936. A Forgotten Chapter in the History of Circulation of the Blood. *Annals of Surgery,* Vol.104 (1), pp. 2–8.

Hamarneh, S. 1972. Pharmacy in Medieval Islam and the History of Drug Addiction. *Medical History,* Vol. 16 (3), pp. 226–237.

Hannam, J. 2011. The Genesis of Science. Regency Publishing. ISBN 1-59698-155-5, p. 26.

Hehmeyer, I. and Khan, A. 2007. Islam's Forgotten Contributions to Medical Science. *Canadian Medical Association Journal,* Vol. 176 (10), P. 1467.

http://www.muslimheritage.com/uploads/Al-Zahrawi_Great_Andalusian_Surgeon.pdf

Islamic Scientific Contributions to Civilization (2014). Retrieved from http://score.rims.k12.ca.us/activity/rosen_islamic_science/

Janin, H. 2006. The Pursuit of Learning in the Islamic World, 610-2003. McFarland and Company; Alternate Edition, ISBN 13: 978-0786429042, pp. 98-99.

Jones, B. 1932. Dictionary of World Biography. The Australian National University (AUN Press), ISBN 9781922144492, p. 193.

Kaf-Alghazal, S. 2007. Ibn-Al-Nafis and the Discovery of the Pulmonary Circulation. Foundation for Science Technology and Civilization. Publication ID 68. Retrieved from

Keys T. E. and Wakim K. G. 1953. Contributions of the Arabs to Medicine. Proceedings of the Staff Meeting, Mayo Clinic; Vol. 28, pp. 423-437.

Loukas, M., Lam, R., Tubbs, R. S., Shoja, M. M. and Apaydin, N. 2008. Ibn al-Nafis (1210-1288): The First Description of the Pulmonary Circulation. *The American Surgeon,* Vol. 74 (5), pp. 440-442.

Lyons, A. S. and Petrucelli, R. J. 1997. Medicine: An Illustrated History. Harry N. Abrams Publisher; Revised Ed., ISBN 13: 978-0810980808, pp. 97 and 101.

Majeed, A. 2005. How Islam Changed Medicine: Arab Physicians and Scholars Laid the Basis for Medical Practice in Europe. *The British Medical Journal,* Vol. 331 (7531), pp.1486–1487.

Masic, I. 2010. On Occasion of 800th Anniversary of Birth of Ibn al-Nafis - Discoverer of Cardiac and Pulmonary Circulation. *Medical Archives,* Vol. 64 (5), pp. 309-313.

Matteo Realdo Colombo: The Italian Physician (2015). Encyclopedia Britannica: Retrieved http://www.britannica.com/EBchecked/topic/126123/Matteo-Realdo-Colombo

Mettler, C. C. and Mettler, F. A. 1947. History of Medicine. The Blakiston Co, Philadelphia, pp. 40-59 and 113- 28.

Meyerhof, M. 1935. Ibn An-Nafîs (XIIIth Cent.) and His Theory of the Lesser Circulation. The University of Chicago Press: The History of Science Society: Isis, Vol. 23, No. 1, pp. 100-120.

Nager, F. 1993. The Mythology of the Heart. La Roch Ltd. Publisher, ISBN 9783907770023, p. 18.

Numan, M. T. 2014. Ibn Al Nafis: His Seminal Contributions to Cardiology Pediatric Cardiology, Vol. 35 (7), pp.1088-1090.

Patwardhan, K. 2012. The History of the Discovery of Blood Circulation: Unrecognized Contributions of Ayurveda Masters. Advances in Physiology Education, *American Physiological Society,* Vol. 36 (2), pp. 72-77.

Qatayyah, S. 1984.The Arabic Physician Ibn Nafis (Published in Arabic). 1st Ed. Beirut: Arabic Corporation for Studies and Publication, pp. 37-43.

Rafiabadi, H. N. 2005. Saints and Saviours of Islam. Sarup and Sons, New Delhi, ISBN 13: 9788176255554, p. 295.

Rosenthal, F. 1970. Knowledge Triumphant: The Concept of Knowledge in Medieval Islam. *Speculum Journal of Medieval Studies,* Vol. 46, No. 3, pp. 542-544.

Sodiq, Y. 2010. An Insider's Guide to Islam. Trafford Publishing, ISBN 10: 1426925603, p. 299.

Stefanadis, C., Karamanou, M, and Androutsos, G. 2009. Michael Servetus (1511-1553) and the Discovery of Pulmonary Circulation. *Hellenic J Cardiol,* Vol. 50, pp. 373-37.

Thomson, W. R. 2014. History of medicine: Harvey and the Experimental Method, Encyclopedia Britannica. Retrieved http://www.britannica.com/EBchecked/topic/372460/history-of-medicine/35659/Harvey-and- the-experimental-method

West, J. B. 1985. Ibn al-Nafis, the Pulmonary Circulation, and the Islamic Golden Age. *Journal of Applied Physiology,* Vol.105 (6), pp. 1877-1880.

Wilkins, R. H. 1992. Neurosurgical Classics. Thieme/AANS Publisher, 1st ed., ISBN 1588901335, pp. 1, 186, 515.

Willerson, J. T., and Teaff, R. 1996. Egyptian Contributions to Cardiovascular Medicine. *Texas Heart Institute Journal,* Vol. 23 (3), pp.191-200.

Zampieri, F., Zanatta, A., Elmaghawry, M., Bonati, M. R., and Thiene, G. 2013. Origin and Development of Modern Medicine at the University of Padua and the Role of the "Serenissima" Republic of Venice. *Global Cardiology Science and Practice,* Vol. 3 (21), pp. 1-14.

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