

Acetyl Salicylic acid and Omega 3 Fatty Acids in the pro resolving pathway of Hypertension

Abstract

Newer mechanisms of action of Acetyl Salicylic acid have been discovered in the proresolving pathway in various disorders. Omega 3 fatty acids are also involved in the synthesis of resolvins via an aspirin triggered pathway. The present review aims to discuss the newly discovered aspirin triggered lipoxins, resolvins, protectins, maresins in the current understanding of pathophysiology of endothelial dysfunction in various cardiovascular disorders, especially hypertension. The concept of aspirin triggered lipoxins (15-epi-LXA₄ and 15-epi-LX₄) counteracting the action of LTB₄, PGE₂, and TXA₂ is discussed. Aspirin triggered lipoxins also block the expression of IL-8 gene. Aspirin is the only known NSAID to induce NO in a dose dependent manner. In this narrative review, we describe the role of acetyl salicylic acid in the pro-resolution pathways that might prevent or reduce the complications in patients with high blood pressure.

Key Words: Acetyl salicylic acid, Cardiovascular System Disorders, lipoxin, resolvin

Background

Aspirin, a term coined by Bayer Pharmaceuticals, is the acetylated form of salicylic acid. Salicylate is a common constituent of numerous medicinal plants that have been used for thousands of years to treat pain and rheumatic fever in Ayurveda. Ancient Egyptians used the leaves of the Myrtle tree to treat rheumatic pain. Hippocrates treated eye infections with extracts from poplar trees and used extracts from willow bark in treating the pain and fever associated with childbirth. Salicylate was first chemically synthesized in 1859 and was widely used as an anti-inflammatory in 1876. Salicylate is unstable, has an extremely bitter taste and causes gastric irritation so researchers set out to develop analogs with same pharmacological benefits but be easier to tolerate upon ingestion. In 1897 Felix Hoffman, at the Bayer pharmaceuticals, discovered the mechanism to acetylate salicylate and thus the advent of aspirin (acetylsalicylic acid)(1,2).

Aspirin was in use for over 70 years and yet its mode of action remained unknown. In 1960 H.O. Collier and colleagues determined that aspirin worked through the pathways involved in the synthesis of the prostaglandins. In 1971, it was discovered that aspirin and other non-steroidal anti-inflammatory drugs (NSAIDs) all exerted their effects through the inhibition of PG synthesis by inhibiting of the bifunctional enzyme cyclooxygenase (there are two forms COX-1 and COX-2). However, the ability of aspirin to limit leukocyte migration into sites of inflammation, thereby dampening the recruitment and march of host inflammatory responses could not be explained only later (3). Aspirin and Fish oil are low cost interventions that can prevent and aid in the resolution of inflammation (4).

Omega 3 Fatty acids in the prevention of Hypertension

Linoleic acid (LA; 18:2 ω -6) and α -linolenic acid (ALA; 18:3 ω -3) are essential fatty acids that are not synthesized by the human body. Docosahexaenoic acid (DHA) is

considered as conditionally essential because of its limited formation from ALA and, jointly with eicosapentaenoic acid (EPA), in prevention of cardiovascular disease(5,6). A high intake of ω -3 PUFA (>3gms/day) has been associated with cardiovascular protective effects improving endothelial function and reducing atherosclerosis (7). Beneficial effects have been observed on blood pressure (BP), lipid profile, and platelet aggregation and also by their anti-inflammatory and proresolution properties. Clinical studies suggest that consumption of ω -3 PUFA may reduce blood pressure in hypertensive subjects and patients with other cardiovascular risk factors such as overweight, hyperlipidemia or in patients treated with hemodialysis (9,10,11). Figure 1 summarizes the clinical benefits of ω -3 PUFA(Figure 1).

Aspirin in the prevention of Cardiovascular Diseases

Cardiovascular Disease is a leading cause of morbidity and mortality worldwide. The pathology is believed to evolve in two stages with endothelial dysfunction and atherosclerosis leading to Hypertension, Myocardial Infarction and Stroke as consequence of systemic inflammation, oxidative stress, and endothelial dysfunction (12,13,14). Endothelial dysfunction is an exaggerated inflammatory response attributed to an unbalanced regulation of innate and adaptive immune responses. Atherosclerosis is deposition subendothelial lipid-filled foam cells, fibrinoid necrosis of the arterial wall, perivascular lymphocytic infiltration, and it is similar to early arteriosclerosis. In the transition phase endogenous protective pathways resolve the initial inflammation preventing atherosclerosis and leading to a normal vessel wall and Blood pressure (Figure 2). Resolution of inflammation is an ongoing process coordinated by mediators derived from Aarachidonic acid, Eicosapentaenoic acid and Docosahexaenoic acid. These include Lipoxins, Resolvins, Protectins and Maresins (15,16). A lipoxin - in is an anti-inflammatory eicosanoids synthesized through the lipoxigenase interactions.

The LXs and Epi LXs also inhibit the actions of the leukotriene Lipoxins have been shown as an anti-inflammatory mediator in human endothelium in both in vivo and in vitro studies (17). If the initial stage of inflammation couldn't be controlled by immune regulation in the endothelium, there is development of oxidative and endoplasmic reticulum stress, release of proinflammatory cytokines, increased anti angiotensin antibodies in the circulation. This leads to endothelial and leukocyte activation in multiple organs. In the cardiovascular system there is hypertension, peripheral edema, pulmonary edema and cardiac failure. In kidneys, there is glomerular endotheliosis resulting in proteinuria and renal failure. In brain, there is cerebral vessel ischemia and stroke (18).

Aspirin Cyclooxygenase Interactions

Aspirin is unique in that it not only has analgesic (pain), antipyretic (fever) and anti-inflammatory effects (exerted at the level of the PG and TX synthesis) but it also exerts beneficial effects on the cardiovascular system via anti-inflammatory pathways distinct from PG and TX inhibition mediated by the salicylate group and the acetyl group (Figure 2). At high doses (300-325 mg three times a day) aspirin functions to block the PG and TX synthesizing activity of COX-1 which results in inhibition of the primary pro-inflammatory, pyretic and pain-inducing action of these eicosanoids (19). At the site of coagulation there is a balance between the levels of platelet derived TXA₂ and endothelial cell derived PGI₂. This allows for platelet aggregation and clot formation but prevents excessive accumulation of the clot thereby maintaining blood flow around the site of the clot (20,21,22). Endothelial cells regenerate active COX

faster than platelets because mature platelets cannot synthesize the enzyme, requiring new platelets to enter the circulation (platelet half-life is approximately 4 days). Thus, PGI₂ synthesis is greater than that of TXA₂. The effect of aspirin is more in favor of endothelial cell-mediated inhibition of the coagulation cascade (23,24,25,26,27).

Classical and aspirin triggered Synthesis of the lipoxins: Lipoxin synthesis from arachidonic acid occurs through several different trans cellular interactions. An initial stimulus activates Phospholipase A₂ that hydrolyzes arachidonic acid from the membrane-associated phosphoinositide. Three pathways exist for the synthesis of the lipoxins. The "classic" pathway involves 5-lipoxygenase (5-LOX, encoded by the ALOX5 gene) activity in leukocytes followed by 12-lipoxygenase (12-LOX, encoded by the ALOX12 gene) action in platelets. The second pathway is the action of 15-lipoxygenase (15-LOX, encoded by the ALOX15 gene) in epithelial cells followed by the 5-LOX action in leukocytes.

The third pathway is that induced by aspirin-mediated acetylation of COX-2. Aspirin can trigger the synthesis of stereoisomers (epimers) of LXA₄ and LXB₄ identified as 15 epi-LXA₄ and 15 epi-LXB₄ (these compounds are also referred to as aspirin-triggered lipoxins (ATLs). In endothelial and epithelial cells the aspirin-induced acetylation of COX-2 alters the enzyme such that it now converts arachidonic acid to 15*R* hydroxyeicosatetraenoic acid (15*R*-HETE). This is rapidly metabolized to the epi-LXs in monocytes and leukocytes through the action of 5-lipoxygenase (5-LOX). COX 2-enzyme initiation of leukotriene synthesis is prevented by acetylation (23,24).

Aspirin Lipoxygenase interaction.

Only at low doses (75mg) aspirin elicits its most important anti-inflammatory benefits. The low dose anti-inflammatory effects of aspirin are due to its ability to trigger the synthesis of the lipoxins (LXs: Epi LXA₄ and Epi LXB₄). Higher doses of aspirin have no significant effect on LX synthesis. (25).

The aspirin-triggered lipoxin synthesis pathway is initiated when activated circulating leukocytes (primarily neutrophils) adhere to the vascular endothelium leading to a tilt in balance towards resolution (Figure 3). The lipoxins LXA₄ and 15 epi-LXA₄ elicit their effects by binding to a specific G protein-coupled receptor (GPCR) originally identified as ALXR. ALXR was originally identified as the formyl peptide receptor-like 1 (FPRL1) protein, a member of the formyl peptide receptor (FPR) family of receptors that bind *N*-formylated peptides derived by the degradation of bacteria or host cells. The ALXR/FPRL1 protein is encoded by the formyl peptide receptor 2 (FPR2) gene (26). The original member of the FPR family (FPR1) recognizes the *N*-formylated bacterial peptide formyl-Met-Leu-Phe. The FPRs are expressed predominantly in phagocytic leukocytes.

LXA₄ and LXB₄ promote the relaxation of the vasculature. Lipoxins and epi-LXs inhibit polymorphonuclear leukocyte (PMN) chemo taxis, PMN-mediated increases in vasopermeability, and PMN adhesion and migration through the endothelium. The LXs also stimulate phagocytosis of apoptotic PMNs by monocyte-derived macrophages. PMN phagocytosis represents the resolution phase of inflammatory events, thus aspirin promotes this process and increases the rate of return to the normal tissue state. This transition phase from inflammation to resolution is impaired

in metabolic syndrome (27,28,29). Lipoxins also lead to a reduction in swelling due to edema by regulating the actions of Histamine (31).

The actions of Epi LXA₄ lead to the production of prostacyclin (PGI₂) and Nitric Oxide (NO). The induction of NO by aspirin is correlated, in a dose-dependent manner, with a reduction in leukocyte accumulation at sites of inflammation. No other NSAID has been shown to exert this effect on NO production making aspirin unique among this class of **drugs** (32,33). Anti-inflammatory actions of the lipoxins and aspirin-triggered lipoxins include blocking expression of the IL-8 gene (a pro-inflammatory chemokine produced by macrophages and endothelial that stimulates neutrophil migration), inhibition of the release and actions of tumor necrosis factor- α (TNF- α), and stimulation of transforming growth factor- β (TGF- β)(34).

Aspirin Induced Lipid Mediators from Omega 3 Fatty Acids

Aspirin also induces synthesis of an additional class of anti-inflammatory lipid mediators known as the resolvins (Rvs) and the protectins (PDs)(35,36,37,38). These immune modulating EPA and DHA derivatives are referred to as Specialized Proresolving Mediators, SPM. Numerous studies have reported the role of omega-3 PUFAs, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in prevention of cardiovascular diseases (39). A combination of aspirin and omega-3 PUFAs is an effective prevention strategy in cardiovascular diseases (40). **The Rv and PD molecules do not inhibit the onset of inflammation but stimulate the resolution pathways.** Nine resolvins and two protectins have been characterized. The resolvins promote the resolution of the inflammatory cycle. The resolvins are divided into two classes with the E-series resolvins (RvE1, RvE2, and RvE3) being synthesized from EPA and the D series resolvins (RvD1–RvD6) being derived from DHA. The resolvins share a 17-hydroxy residue that is introduced into DHA by the lipoxygenase, 15-LOX. Several of the resolvins are synthesized in epimeric form via the effects of aspirin. The levels of RvE1 increase spontaneously in individuals taking aspirin or consuming EPA. RvE1 is produced in a trans cellular manner involving endothelial cells and leukocytes. Within the endothelium EPA is converted to 18R-HEPE (18R-hydroxyeicosapentaenoic acid) by the COX-2 enzyme following its exposure to aspirin (Figure 4). The 18R-HEPE is released by the endothelial cells and taken up by adherent leukocytes where 5-LOX converts it to RvE1. The E series resolvins reduce inflammation, regulate PMN infiltration by blocking trans endothelial migration, regulate interleukin 12 production and lead to resolution of the inflammatory responses. RvE1 stimulates the phagocytosis of apoptotic PMNs by macrophages. RvE1 is also selectively disrupts thromboxane-mediated platelet aggregation.

The protectin identified as (N) PD1 (where the N refers to neuroprotectin) is derived from DHA through the actions of the lipoxygenase, 15-LOX and then enzymatic hydrolysis. Aspirin can trigger the formation of an epimeric PD1 molecule identified as AT-PD1. The protectins (N) PD1 and AT-PD1 have been shown to exert potent inflammation resolving actions by inhibiting T cell and PMN chemotaxis, by promoting T cell apoptosis, by decreasing TNF α and INF- γ secretion, during ischemia-reperfusion injury. Thus an Aspirin and omega 3 fatty acid combinations not only prevents the onset of inflammation but also resolves it.

Maresins, named maresin 1 (MaR1) and maresin 2 (MaR2), are produced from DHA, when the lipoxygenase, 12-LOX acts on DHA. **Ma re sins** are produced by macrophages and so the name “maresin” means macrophage mediator **resolving**

inflammation. Maresin 1 has anti-inflammatory, pro-resolving, analgesic and wound healing potencies. Maresin 1 mainly acts on vascular smooth muscle cells and vascular endothelial cells. In vascular smooth muscles and endothelium, Maresin 1 prevents the adhesion of monocytes to the endothelium induced by tumor necrosis factor alpha (TNF α). Maresin 1 also reduces the production of reactive oxygen species (ROS) by vascular smooth muscle cells and endothelial cells. The main pathway, through which Maresin 1 exerts its effects, is through down-regulation of the transcription factor, nuclear factor kappa-light-chain-enhancer of activated B cells (NF- κ B), in the vascular smooth muscles and vascular endothelium.

Maresin 2 has potent efferocytosis properties. It has been shown to reduce neutrophil infiltration and to enhance efferocytosis, the macrophage-mediated phagocytosis of dead and dying cells. The process of efferocytosis plays an important part in clearing of inflammation. In addition, when maresins produced by macrophages are released and acted upon by platelets, two related structures termed the maresin-like mediators (MaR-L1 and MaR-L2) are produced.

There are numerous DHA-derived bioactive lipid mediators in addition to resolvins, protectins, and maresins. Other DHA-derived Bioactive lipids are the electrophilic Oxo-derivatives (EFOX) which exert anti-proliferative and anti-inflammatory effects; the neuroprostanes (NP) which have wound healing and cardio protective effects; the epoxides which have analgesic and antihypertensive effects; the ethanol amines which exhibit neuromodulator, immune modulatory, and metabolic effects; the fatty acid esters of hydroxy fatty acids (FAHFA) which lead to inflammation proresolution and the *N*-acyl amides which have the neuroprotective and metabolic regulatory effects.

Current recommendations of aspirin

The US preventive Task force recommends the use of aspirin for the primary prevention of cardiovascular diseases (CVD). Aspirin is recommended for men age 45-79 to reduce the risk of myocardial infarction when a net benefit is present. A net benefit means that the potential benefit from taking the aspirin outweighs the harms, mainly gastrointestinal (GI) bleeding. Aspirin is recommended for women age 55-79 to reduce the risk of ischemic stroke when a net benefit is prevented(39). The USPSTF recommends against the use of aspirin in men<45 and women<55, and also in men and women aged more than 80. Online calculators can be used to predict the 10 year CHD risk in men (<http://hp2010.nlm.nih.gov/atpiii/calculator.asp>) and women (<http://www.westrenstroke.org>).

Another indication of aspirin is prevention of pregnancy-induced hypertension. The USPSTF recommends the use of low-dose aspirin (81 mg/d) as preventive medication after 12 weeks of gestation in women who are at high risk for preeclampsia. (B recommendation)(40,41,42). If the woman is identified to be high risk later in pregnancy Aspirin still needs to be started as various multi centric stratified comparisons did not show that the timing of aspirin initiation (<16 weeks) or dosage had any effect on reducing the efficacy of aspirin for the prevention of preeclampsia (43,44). Evidence does not suggest benefit of starting aspirin earlier (12 -16 weeks) rather than later in pregnancy. World health Organization recommends the use of low dose aspirin (75 mg) as early as 12 -20 weeks of gestation for high risk women (previous preeclampsia, diabetes, chronic hypertension, renal or auto immune disease, or multifetal gestation). There is limited evidence regarding the benefit of aspirin in low risk women (43).

The National Institute for Health and Care Excellence recommends that women at

high risk for preeclampsia (i.e., those with a history of hypertension in a previous Pregnancy, chronic kidney disease, autoimmune disease, type 1 or 2 diabetes, or chronic hypertension) take 75mg/d of aspirin from 12 weeks until delivery. It recommends the same for women with more than one moderate risk factor (first pregnancy, age >40 years, pregnancy interval>10 years, body mass index >35 kg/m², family history of preeclampsia, or multifetal pregnancies) (44). The American Heart Association and the American Stroke Association recommend that women with chronic primary or secondary hypertension or previous pregnancy related hypertension take low-dose aspirin from 12 weeks until delivery. The American Academy of Family Physicians recommends low-dose aspirin (81 mg/d) after 12 weeks of gestation in women who are at high risk for preeclampsia . Another clinical use of low dose aspirin (75-81mg/day) is diagnosed antiphospholipid antibody syndrome. Antiphospholipid antibody syndrome is characterized by clinical evidence of vascular thrombosis and obstetrical complications like early pregnancy miscarriage, intrauterine growth restriction, preeclampsia and preterm births (45,46). Serology study reveals persisting antiphospholipid antibodies on two occasions 6 weeks apart. The diagnosis of obstetric antiphospholipid antibody syndrome includes presence of both clinical and serological criteria (47). The pathophysiology involves activation of endothelial cells, platelets, monocytes and complement pathways (48). The anticoagulant proteins are inhibited. It has been suggested that the obstetric complications are associated with placental ischemia and inflammation rather than thrombosis at the fetomaternal interphase (49,50,51). Low dose aspirin with low molecular weight heparin is the preferred treatment in pregnancy with antiphospholipid antibody syndrome (52,53). Contraindications to aspirin prescription are documented allergy to aspirin, asthma, bleeding disorders and gastritis. G6PD enzyme deficiency is a relative contraindication though long-term low dose aspirin has been found to be safe (54).

Conclusion

Aspirin is a low cost intervention that can prevent the metabolic syndrome atherosclerotic vessels by its anti-inflammatory, antiplatelet and Proresolving abilities. Recent understanding of the pathophysiology of Hypertension and proresolving pathways can help to understand the rational use of aspirin in prevention and reducing the complications of high blood pressure. A combination of aspirin and omega 3 fatty acids has potential benefits. DHA metabolites have been found to have potent role in the resolution pathway of inflammation. Future endeavors would focus on the identification of subset of high-risk hypertensive patients who will benefit most from aspirin, omega 3 fatty acids and DHA. Different dosage and time of initiation in various high-risk groups needs to be identified. Further research is also required to identify the correct time and the oral doses that will help in minimizing the long-term risk of future cardiovascular diseases.

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481 Figure Legends

482 Figure 1: The Three Phases: Inflammation, Transition and Resolution. Endogenous
483 protective pathway resolves the initial inflammation leading to prevention of
484 atherosclerosis In the transition phase endogenous protective pathway resolve the
485 initial inflammation preventing atherosclerosis and leading to a normal vessel wall and
486 Blood pressure.

487 Figure 2: Omega 3 fatty acid: Biological effects

488 Figure 3: Aspirin-triggered lipoxin synthesis pathway is initiated when activated
489 circulating leukocytes (primarily neutrophils) adhere to the vascular endothelium and
490 balance is tilted towards Resolution.

491 Figure 4: Aspirin and Omega 3 fatty acids prevent the onset of inflammation by the
492 release of Aspirin triggered Lipoxins, Protectins, Resolvins and Maresins.

493 Scheme 1: Pathways to show how a diet rich in omega 3 fatty acids and aspirin may
494 have a role in improving vascular endothelial dysfunction.
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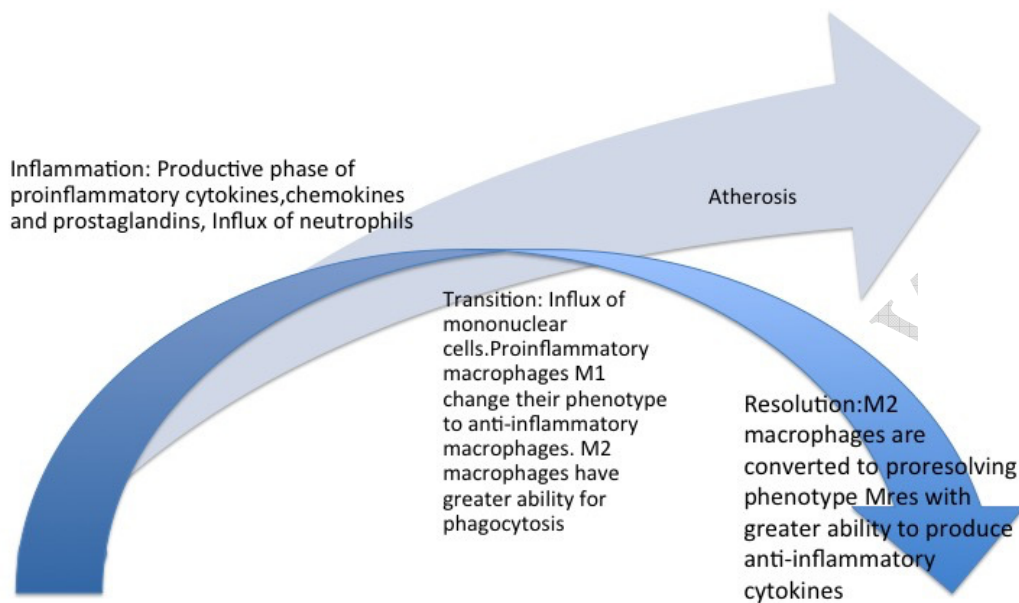
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509 Figure 1:

Under peer review



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511 Figure 2

Possible Biological effects of omega3 Fatty Acids

Series 3 prostaglandin production with vasoactive, antiplatelet and anti-inflammatory effects

Interaction with omega 6 pathways

Suppression of aldosterone secretion

Changes in intracellular signal transduction, reduction in plasma viscosity and in the activity of angiotensin converting enzyme

Increased production of endothelial Nitric oxide

Changes in ion channels with influence on the parasympathetic stimulation of vagus nerve reducing heart rate

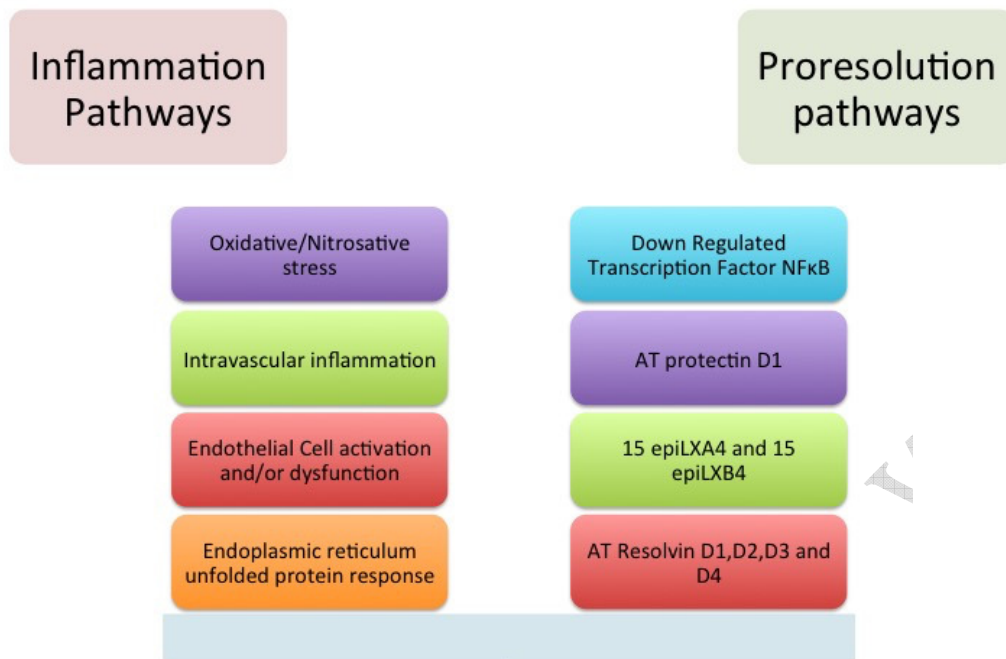
Changes of myocyte cell membrane improving left ventricular diastolic function

Inhibition of transforming growth factor beta synthesis

Vascular smooth muscle apoptosis and prevention of vascular wall fibrosis and secondary hypertension development

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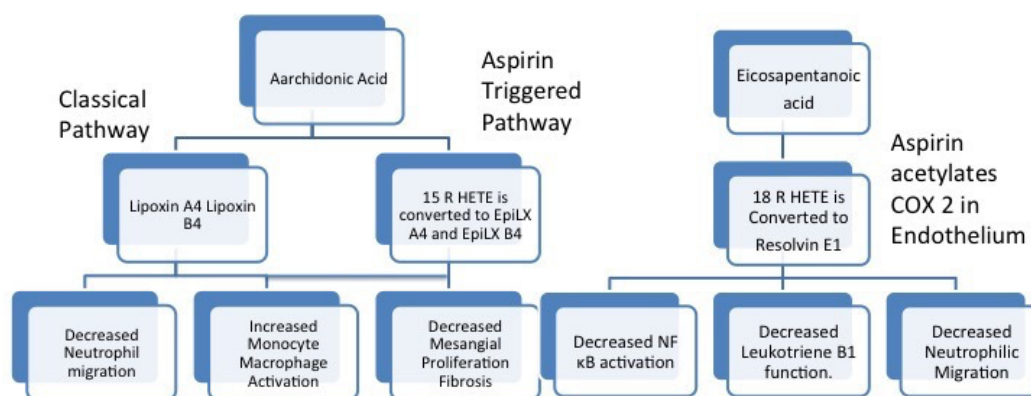
513 Figure 3



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516 Figure 4



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