

ORIGINAL ARTICLE



# Osteogenesis of heart valves – An immune mediated Rheumatic inflammation

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## ABSTRACT

Mineralization is the hardening of the valve due to the deposition of calcium salts resulting osteogenesis as bone formation. Any valve can become calcified. However, calcification is more likely to affect the valves on the left side of the heart (mitral and aortic valves) since they experience greater pressure, and more wear-and-tear damage. Calcification earlier in life was seen in severely damaged valves by the rheumatic process and therapeutic strategies are targeted to reverse this process by understanding its biological mediators.

## KEY WORDS

Rheumatic inflammation;  
Mineralization of heart valves;  
Cellular process; Osteogenetic  
bone formation;  
Echocardiographic features;  
Therapeutic interventions

## ARTICLE HISTORY

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## Introduction

The senile valve calcification also known as 'dystrophic calcification', occurs on the heart valves usually in adults over 50 years of age. Calcification of valves is a complex process and involves different cell types and matrix architecture of heart valves. The normal aortic valve is made up of 3 cusps and its arrangement results in even distribution of mechanical stress to the valve ring and the aorta [1]. At their base, the valve leaflets are attached to a dense collagenous network, called the annulus, which facilitate their attachment to the aortic root and the dissipation of mechanical force. The anterior mitral leaflet is in direct continuity with left half of non-coronary cusp and the adjacent third of left coronary cusp. The mitral-aortic intervalvular fibrosa is the junctional tissue between the elements of mitral and aortic valves, called as mitral-aortic membrane or curtain. It is relatively avascular and offers little resistance to infection [2].

Historically, calcification of valves occurs due to prolonged 'wear and tear' and age-related valvular degeneration, but recent evidence suggests that it is the result of active inflammatory process [3] leading to osteogenesis by involving biochemical, humoral and genetic factors similar to skeletal bone formation and it is the most common manifestation of rheumatic heart disease. The anterior mitral leaflet - aortic cusp continuity region was particularly affected by this mineralization process and so this case had been reported.

## Case Report

A 52-year-old male, admitted with sudden onset of palpitations with a history of rheumatic fever during childhood and dropped penicillin prophylaxis for 10 years. He married at the age of 26 years and had 5 healthy children. Pulse rate was 75 bpm and irregular and blood pressure 110/70 mmHg. Cardiac examination revealed a heaving apical impulse in the left 5th space at anterior axillary line, varying intensity of first heart sound with a mid-diastolic murmur at the apex and grade 4/6 mid-systolic murmur well heard at the apex as a conduction conduction from right second intercostal space where its intensity is maximum due to 'Gallavardin' phenomenon as a

dissociation between harsh, noisy, low frequency components at the right second space, transmitted to neck vessels as 'carotid shudder' and high frequency musical components at the apex as a 'musical murmur'. Blood chemistry was normal including the lipid profile. ECG showed atrial fibrillation and LVH (left ventricular hypertrophy pattern) as shown in Figure 1. X-ray chest revealed concentric LVH and ascending aorta dilation as shown in Figure 2. Transthoracic 2D echocardiography revealed the dense calcification of anterior mitral leaflet and aortic valve as shown in Figures 3 to 7 as a result of rheumatic inflammation. The patient was treated with verapamil tablets 40 mg three times daily to keep the rhythm under control and advised early double valve replacement along with lifelong penicillin prophylaxis.

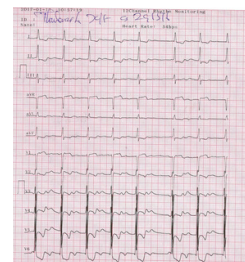


Figure 1. ECG showing the 'atrial fibrillation' with LVH (left ventricular hypertrophy).

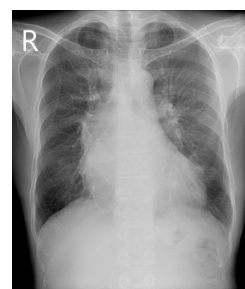


Figure 2. X-ray chest PA (postero-anterior) view showing concentric LVH (left ventricular hypertrophy) and dilated ascending aorta.

## Review of Literature

Lazare Riviere, a French physician in 1663, identified large caruncle-like masses obstructing the left ventricular outflow to the aorta in necropsy findings as an earliest description of calcific aortic stenosis [4] and the calcified mass was originally attributed to endocarditis. In 1846, Hass suggested a degenerative process occurred within the valve itself to initiate ossification. In 1904, Moenckeburg found that the aortic valve calcification occurred as a result of calcium deposition on the valve cusps due to degeneration within the layers of valve leaflets or extension of sclerotic changes of aorta to valve cusps. In 1924, Dr. Carey Coombs described the inflammatory lesion in the rheumatic valve leaflets and the presence of new vessels developing within the valves [5]. In 1931, Christian first described that aortic stenosis with calcification of the cusps was possibly of rheumatic origin [6]. In 1938, Clawson, Noble and Lugkins stated that the 'calcified aortic nodular deformity' was predominantly of a rheumatic nature [7]. In 1939, Dry and Willius concluded that the etiologic factor of calcification was rheumatic [8] and Hamburger and Saphir found evidence for both a rheumatic and nonrheumatic origin [9]. In 1961, Edwards discussed the occurrence of calcification in stenotic rheumatic valves [10].

## Pathogenesis

Rheumatic heart disease is the most common cause of valvular heart disease in tropical nations such as India. Rheumatic valve calcification is not a random passive process, but it is a regulated, inflammatory cellular process associated with the expression of osteoblast markers and neo angiogenesis. Early stage of calcification is in a manner akin to atherosclerosis. Once the osteoblast activity has been established, the disease progression is more likely to be regulated by the mediators of calcium homeostasis [11]. A similar osteoblast-like process that occurs in degenerative calcific valve develops in the calcific process of rheumatic valves [12]. The cellular and molecular mechanisms that involves the valve, circulating and bone marrow derived cells have been implicated in the pathogenesis of calcification. The cellular differences between the rheumatic and degenerative lesions are the intense inflammatory infiltrate and VEGF (vascular endothelial growth factor) expression in areas of neo angiogenesis found in rheumatic valves compared to degenerative valves. The cardiovascular risk factors such as exposure to biochemical (hypercholesterolemia, hyperglycemia) or mechanical (hypertension) may disrupt the normal cellular and matrix architecture of the valve, produces an inflammatory tissue milieu, atherosclerosis like lesions, osteoblastic transformation and calcification process. The key mediators of valve calcification are shown in table 1.

**Table 1.** Key mediators of valve calcification.

| S.No. | SIRS Criterion                                                        |
|-------|-----------------------------------------------------------------------|
| 1     | VECs (valve endothelial cells) to mesenchymal transition              |
| 2     | VICs (valve interstitial cells) to osteoblast-like bone forming cells |
| 3     | Matrix vesicle formation gives rise to micro calcific nodules         |
| 4     | Lipid accumulation                                                    |

These mediators promote neo angiogenesis, extracellular matrix remodeling, fibrosis and calcification of valve leaflets.

Calcification of heart valves is an immune-inflammatory disease process. The rheumatic involvement produces an inflammatory tissue environment that disrupts the endothelial layer of valve leaflets in a mechanism similar to that in atherosclerosis. The endothelial disruption may allow the lipids, including low-density lipoproteins, apolipoprotein B, (a) and E<sub>2</sub> to penetrate and accumulate in areas of inflammation and undergo oxidative modification. These oxidative lipoproteins are highly cytotoxic, capable of stimulating intense inflammatory activity and subsequent mineralization [13]. The VECs (vascular endothelial cells) are activated and the expression of adhesion molecules that facilitate recruitment and trans-endothelial migration of monocytes which differentiate into macrophages, and infiltration of T-lymphocytes and  $\alpha$ -actin expressor cells. The macrophages release matrix metalloproteases and cysteine endoproteases that lead to degradation of collagen and elastin in the valve matrix to disrupt the normal valve architecture [14]. The T-cells release proinflammatory cytokines, including transforming growth factor- $\beta$ , tumor necrosis factor- $\alpha$  and interleukin-1- $\beta$  which induce myofibroblast activation and cellular proliferation, ultimately help to stimulate and establish subsequent fibrotic and calcification processes that drive increasing valve stiffness [15,16]. Increased levels of activated CD8 cells (cytotoxic T-cells or natural killer cells) and memory effector cells in patients with calcified valves may indicate a systemic adaptive immune response on valve calcification [17]. Lrp5, a coreceptor of the family of LDL receptors, has been found to regulate cellular proliferation and bone formation in valvular tissues [18]. Genetic bone markers have been found to be important in the development of osteoblast bone formation, a process that precedes calcification [19]. Lp(a) levels mediate the effect of SN rs10455872 in the gene LPA in valvular calcification. The Kringle IV type 2 (KIV-2) repeats at LPA locus, which encode apolipoprotein (a) and its variation determines the plasma Lp(a) levels. NOTCH 1 on chromosome 9q34-35 is a susceptibility locus for bicuspid aortic valve and accelerates valvular calcification [20]. At the site of endothelial damage, the endothelial progenitor cells participate in the repair process by transiently establishing residence and secreting factors that facilitate proliferation and migration of resident endothelial cells [21]. In calcified valves, these progenitor cells are dysfunctional and express increased proapoptotic caspase -3 activity and decreased telomeric - repeat binding factor-2 (TERF2) expression, indicating progenitor cell senescence [22]. The VECs (valvular endothelial cells), lose the endothelial cell properties, no longer express endothelial-specific markers such as cadherin, plectin-like pleomorphism characteristic of mesenchymal cells or myofibroblasts and express  $\alpha$ -smooth muscle actin, type I collagen and vimentin [23]. The transforming growth factor- $\beta$ , transcription factor Msx2 and  $\beta$ -catenin signaling increase the motility and migration of these 'transformed' VECs into the surrounding tissues [24]. Once the endothelial-to-mesenchymal transition (EnMT) occurs, the BMP 2 and 4 (bone morphogenic proteins) secreted by the activated endothelial cells stimulate the calcification by activating Smad and Wnt/B-catenin signaling and upregulate the expression

of osteochondrogenic transcription factor *Msx2* and the faster osteoblast transcription factor *Runx2* [25]. Once *Runx2* is expressed, the cells are committed to an osteoblast lineage, upregulated the expression of calcification-related proteins (osteopontin, bone sialoprotein II, osteocalcin) and undergo calcification [26]. A subpopulation of VICs (valve interstitial cells) become activated in the inflammatory zone of the valve and differentiated into myofibroblasts. These myofibroblasts secrete matrix metalloproteinases which play a role in the restructuring of valve leaflet matrix and responsible for accelerated fibrosis in this process [27]. Under the influence of signaling pathways, Wnt-3-Lrp5- $\beta$  catenin [28], OPG/RANK/RANKL pathway (osteoproteogen/receptor activation of nuclear factor kappa B/RANK ligand [29], *Runx-2*/NOTCH1, activated by BMPs, the myofibroblasts undergo differentiation into osteoblasts, which subsequently coordinate calcification as a part of a highly regulated process akin to new bone formation and mineralize to form calcific nodules on the valves. The local environment drives the mesenchymal progenitor cells to undergo osteogenesis differentiation, elaborate bone matrix in the valve [30] and capable of contributing to valve calcification.

The transition of valvular cells to an osteoblast-like phenotype is not a mutually exclusive process and these osteoblast-like cells may actively generate vesicles or undergo apoptosis to accumulate calcium and form microcalcifications. Matrix vesicles (100 to 300nm) are derived from plasma membrane of smooth muscle cells, encapsulate the calcium inhibitors (MGP- vitamin K dependent matrix Gla protein, Fetuin A- a liver derived protein, osteoproteogens), sequester, render them inactive [31] and serve as a nidus for calcium deposition [32]. Calcifying nanoparticles (10-500nm in size) consistent with nanobacteria [33,34] which nucleate, crystallize and function as a nidus for matrix calcification [35]. The activated matrix metalloproteinases (1,2,3 and 9) and cathepsins (S, K, V and G) degrade the collagen and elastin, compromises valve integrity, augment the inflammatory response and allows for the expansion of calcified nodules [36]. By the end stage of the disease, maturation of valve calcification occurs with lamellar bone and hemopoietic tissue and it is sustained by neo angiogenesis. The new vessels localizing to the region of inflammation and surrounds the calcific deposits. Both intercellular adhesion molecule-1 and vascular cell adhesion molecule-1 expression is increased in these vessels, suggesting that they act as an important portal of entry of inflammatory cells [37]. The mast cells get degranulated in calcified valves and release tryptase which degrade the angiogenesis inhibitor endostatin [38] and down regulation of local angiogenesis inhibitors such as chondromodulin-1 and pronomodulin-1 have been occurred. Once neovascularization has been established, the network of newly formed vessels, expressing the endothelial markers Tie-2, vascular endothelial growth factor receptor-2, smooth muscle  $\alpha$ -actin, facilitate rapid transit of inflammatory cells and procalcific signaling molecules and, these inflammatory lesions in rheumatic valvular disease is associated with angiogenesis and osteogenesis which may contribute disease progression and valvular mineralization.

### Echocardiographic features

The genesis of calcification in aortic valve is always rheumatic [39] and the calcific extension to the mitral valve resembles J-shaped as shown in Figure 7. Calcification resembling a string of pearls in both aortic and mitral valves are typical of

endocarditis. Calcification of mitral-aortic membrane has been reported as highly suggestive of radiation-induced lesions [40] and a pathologic echo density of anterior mitral leaflet is its characteristic feature [41]. But the dense calcification of anterior mitral leaflet as a bone-like structure was observed due to rheumatic mineralization as shown in Figures 3 and 4 along with calcification of aortic valve as in Figures 5 to 7 and in short axis view in Figure 8.



**Figure 3.** Parasternal long axis view showing the dense calcification of anterior mitral leaflet (AML) with commissural fusion in a 52-year-old male.



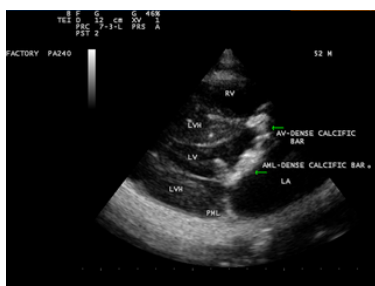
**Figure 4.** Parasternal long axis view showing the anterior mitral leaflet as a dense calcific bar with opening of the stenotic mitral valve in a 52-year-old male.



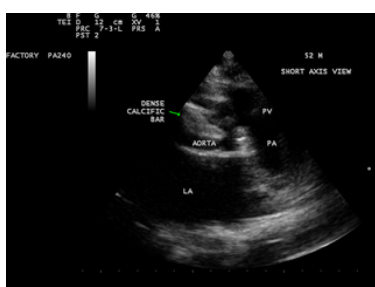
**Figure 5.** Parasternal long axis view showing the calcific bar of anterior mitral leaflet and aortic valve in a 52-year-old male.



**Figure 6.** Parasternal long axis view showing the calcific extension of aortic valve to anterior mitral leaflet in a 52-year-old male.



**Figure 7.** Parasternal long axis view showing the J-shaped appearance of mitral-aortic calcification in a 52-year-old male.



**Figure 8.** Short axis view showing the dense calcific bar in the aortic valve visible as calcium stone in a 52-year-old male.

The degenerative disease, as an aging process frequently involving the aortic and mitral valves and the central fibrous body is called as 'Lev's disease. Lenegre's disease primarily involves the conduction system without affecting the fibrous skeleton of the heart. Both these conditions mostly result in isolated chronic heart blocks in adults. Degenerative calcification of mitral annulus may cause annular mitral stenosis in elderly and the difference between the annular mitral stenosis and rheumatic mitral stenosis [42] was shown in Table 2.

**Table 2.** Difference between annular mitral stenosis and rheumatic mitral stenosis.

| Annular mitral stenosis                     | Rheumatic mitral stenosis                             |
|---------------------------------------------|-------------------------------------------------------|
| Heavy calcification at the base of leaflets | Calcification of leaflets mainly at the tips          |
| Leaflet tips are free                       | Leaflet tips thickened                                |
| Leaflets open without dooming restriction   | Restricted diastolic opening of leaflets with dooming |

### Therapeutic strategies

It is now clear that there is an active biology that leads to stiffening and calcification of valve leaflets [43] and so the valvular calcification is a biologic process.

Lipoprotein (a) has been shown to accumulate in both early and end-stage aortic valve lesions and to co-localize with calcium deposition [44]. In atherosclerosis, inflammation and lipid deposition are the key components in both development of arterial plaque and its stability. Adverse events are predominantly related to plaque rupture, and much of the benefit from statin therapy is due to plaque stabilization and a thickening of the fibrous cap. Lowering Lp(a) levels during early -stage aortic valve disease, with the use of either niacin [45] or novel specific Lp(a) inhibitors [46] can slow the progression to aortic stenosis. Lipid-lowering with HMG-Co A

reductase inhibitors (statins) has been shown to decrease inflammatory cell infiltration, osteoblast bone markers (alkaline phosphatase and Runx2) and downregulated lipoprotein receptor-related protein 5/ $\beta$ - catenin signaling to decrease valve calcification in rabbit models [47]. Despite these findings, 3 large-scale clinical trials (SEAS-Simvastatin and Ezetimibe in Aortic Stenosis [48], SALTIRE- Scottish Aortic Stenosis and Lipid Lowering Trial [49] and ASTRONOMER (Aortic Stenosis Progression Observation: Measuring Effects of Rosuvastatin) [50] failed to show a benefit for statins to limit the progression of aortic valve calcification. Also, statins are known to promote osteoblast differentiation and calcification [51]. Lowering of lipid levels may decrease calcium deposition and, halt the progress of valve calcification, but did not reverse the established calcification or valve dysfunction [52]. When the valvular interstitial cells (VICs) become osteoblast-like cells, statins may actually have a procalcifying effect.

### Warfarin

Warfarin is an inhibitor of  $\gamma$ -carboxylase and vitamin K epoxide reductase, inhibits MGP (matrix Gla protein- an inhibitor of bone morphogenic protein (BMP) signaling [53]) activity and was shown to promote valvular calcification [54].

### Fetuin A

It is a potent circulating inhibitor of calcification [55], acts by binding the cluster of calcium and phosphate to stabilize these ions and prevent uptake by cells and its deficiency was associated with valvular calcification [56]. Therapies with fetuin A show a potential in inhibition of valvular calcification [57].

### ACE inhibitors

The stenotic valve is characterized by extensive thickening due to the accumulation of fibrous tissue and remodeling of the extracellular matrix. Myofibroblasts infiltrate the myocardium, secrete extracellular matrix proteins and accelerate the fibrosis, which is an integral part of the hypertrophic process [58]. The increased afterload in aortic stenosis serves as an additional load on the left ventricle and is associated with increased hypertrophic remodeling and LV dysfunction [59], leading to increased apoptosis. Myocardial ischemia occurs due to increased afterload and coronary flow reserve is impaired since the density of the coronary capillary network does not expand sufficiently to meet the demand in this pathological hypertrophy, in contrast to physiological hypertrophy in which the density of capillary network expand sufficiently. Areas of fibrosis are observed to co-localize with areas of myocyte apoptosis and drive the decompensation of the hypertrophic myocardial response. The rennin-angiotensin system is thought to modify the fibrotic process. Tissue angiotensin-converting enzyme (ACE) and angiotensin II are upregulated in stenotic aortic valves and angiotensin receptors have been identified on valve myofibroblasts [60]. Polymorphism of the ACE 1/D gene have been associated with variations in left ventricular mass [61]. Beneficial effects with respect to hypertrophy, on valve narrowing [62], reduction in mortality and cardiovascular events [63] and less pronounced valve remodeling [64] were observed in patients with aortic stenosis,



maintained on ACE inhibitors and angiotensin receptor blockers. There is evidence that angiotensin receptor blocker therapy inhibits the development of atherosclerosis as well as myofibroblast and osteoblast trans-differentiation in rabbit aortic valves suggests that this drug class may be helpful in slowing aortic stenosis progression [65]. The blood pressure-lowering effect of ACE inhibitors reduces the mechanical stress and strain on the aortic valve and play a role in slowing the aortic stenosis progression by reducing inflammation, stabilizing plaque formation and mitigating the fibrotic process [66].

### Desnosumab

The OPG/RANK/RANKL axis appears to have a central regulatory role in both calcification and osteoporosis, which coordinate calcium homeostasis via the action of osteoblasts and osteoclasts. OPG (osteoprotegerin) is a decoy receptor of RANKL, a potent stimulator of osteoclast differentiation and bone resorption [67]. Increased expression of RANKL (receptor activator of nuclear factor kappa B ligand) and reduced levels of OPG has been also observed in stenotic aortic valves similar to osteoporosis. Inactivation of OPG in mice develops extensive vascular calcification [68]. The development of anti-RANKL monoclonal antibody desnosumab promising a strong rationale in the treatment of aortic stenosis.

### Bisphosphonates

Calcification is a critical process in determining the progress of valvular stenosis and an overlap in pathophysiology between the aortic stenosis and osteoporosis provide a rationale for drugs such as bisphosphonates to reduce the valvular calcium, especially in patients with renal failure and bioprosthetic valves [69,70]. However, it had no effect on freedom from aortic valve replacement or survival [71].

### Gene transfer

By understanding the cell biology of valvular calcification, gene transfer or cell-based therapies are investigated to modulate the cellular mechanism of calcification. The expressing Runx2 in VICs (valvular interstitial cells) commits these cells to an osteoblast-like phenotype. Gene transfer of small interfering RNA that targets Runx2 using adenovirus or recombinant nonviral vectors have been shown to prevent calcification both in vitro and in vivo [72,73]. Heterotopic ossification (HO) is characterized by pathologic endochondral bone formation at nonskeletal sites. Angiogenesis and osteogenesis are highly coupled during bone development. In the process of osteoblast differentiation, a set of bone specific genes (ALP-alkaline phosphatase, osteocalcin) are activated. Run-related protein 2 (Runx2) is a key regulator of these genes, cooperate with BMP-specific R-smads and it is considered as a molecular switch (myoblasts to osteoblasts phenotype) in osteoblast biology. Hypoxia is able to upregulate BMP<sub>2</sub> in osteoblasts via the activation of Hif1  $\alpha$  signaling pathway. Inhibition of Hif1  $\alpha$  (hypoxia induced factor 1  $\alpha$  leads to reduce vessel formation, which may facilitate migration of host mesenchymal stem cells to the bone regeneration site. Synergistic inhibition of endochondral bone formation by silencing the angiogenic factor (Hif1  $\alpha$ ) and osteogenic factor (Runx2) by using the RNA interference technology, allow to design more targeted therapies to inhibit angiogenesis and osteogenesis [74]. miRNAs

(microRNAs) have essential roles in osteoblast differentiation and heterotopic ossification. miR-203 is involved in these processes by repressing Runx2 expression in the post-transcriptional level. Therapeutic overexpression of miR-203 in osteoblasts may reduce heterotopic ossification and even prevent this disorder [75]. Cotransduction of small or short interfering RNA (siRNA) against Runx2 and Hif1  $\alpha$  to inhibit heterotopic ossification have been evaluated. TNP-470 is an antiangiogenic agent that inhibits the neovessel formation and TNP-70 inhibits the biological activity of BMP<sub>2</sub> in early stage of bone induction. A potent delivery of a nanocomposite consisting of serum-soluble DOTAP/siRNA/PPAA-g-1% jeffamine formulation was shown to halt the osteogenic switch driven by BMP<sub>2</sub> by silencing the Runx2m, the downstream mediator of BMP<sub>2</sub> [76].

### Investigational therapy

Osteoclast-like cells are identified in calcified lesions, which in turn capable of resorbing mineral deposits [77]. Thus, strategies to promote osteoclast recruitment or stimulate differentiation of monocytes and macrophages toward an osteoclast phenotype are the areas of active investigation.

Strategies by delivering stem or progenitor cells via direct injection of small molecule inhibitors, osteoclasts, osteoclast-like cells or molecules that promote the transition of resident monocytes/macrophages towards an osteoclast lineage or viral vectors encoding inhibitory RNA (Runx2, Msx2) in areas of aortic valve lesions or to ischemic myocardium using a NOGA-guided catheter system [78] are under investigation.

### Lonafarnib

Mutations in laminin A gene results in the production of a mutant Lamin A protein, progerin, a component of nuclear envelope which become unstable, leading to cell death prematurely. The syndromes associated with these defects are called as 'laminopathies' (Hutchinson Gilford Progeria Syndrome (HGPS), Wiedemann-Rautenstranch syndrome, Restrictive dermopathy) [79]. In progeria, calcific aortic stenosis represents a degenerative premature aging process and principally involving the anterior mitral valve and proximal aortic valve cusps [80]. Systemic hypertension is common and appear before the child reaches the age of 5, and high mortality related to myocardial infarction and heart failure may occur.

Farnesylation is essential for the function of both mutant and nonmutant Lamin A protein, including progerin. Lonafarnib is a farnesyl transferase inhibitor that blocks the posttranslational farnesylation of prelamin A, an experimental drug under trials [81]. Another treatment attempted is a combination of two molecules-Zoledronic acid and pravastatin.

### Interventional therapy

Balloon mitral valvotomy (BMV) is the procedure of choice for severe mitral stenosis when the valve morphology is feasible. However, BMV is contraindicated in bicommissural calcification since it results a high probability of leaflet tear with acute severe mitral regurgitation. BMV can be performed safely and successfully in incommensurably calcified mitral valves [82].

An emergency percutaneous transatrial balloon mitral commissurotomy is a life-saving procedure in a valve with unfavorable morphology, presented with cardiogenic shock in critical calcific mitral stenosis [83,84].

### Transcatheter valve implantation

TAVR (transcatheter aortic valve replacement) was approved by FDA (Food and drug administration) for high-risk surgical candidates in June 2012. There is an increase in risk of stroke due to thrombotic embolic material from the calcified valve. Tissue and vascular damage results in severe paravalvular regurgitation, which is poorly tolerated in hypertrophied left ventricle leading to increase in mortality [85]. The surgical risk for mitral valve replacement is very high due to the comorbidities and technical challenges related to calcium burden. Guerrero, et al reported the first-in-human percutaneous implantation of a balloon – expandable transcatheter valve in a native mitral valve [86]. The use of newer aortic THV technologies such as Lotus (Boston Scientific Corporation) and direct flow valves (direct flow medical) in the mitral position for severe MAC (mitral annular calcification) [87] and improved outcomes were observed [88].

### Surgical therapy

Aortic valve replacement surgery remains the only established treatment for symptomatic aortic stenosis patients [89]. Hemodynamically significant asymptomatic patients will develop symptoms within 5 years; the issues of medical management and surgical correction may pay a close attention to the researchers [90]. Presence of moderate or severe valvular calcification identifies the patients with poor prognosis who may benefit from early valve replacement before the development of symptoms [91]. It is to be determined whether this benefit outweighs the risk of surgery [92].

Calcific mitral stenosis with severe mitral annular calcification may present a different challenge to the surgeon. Extensive debridement of calcium may increase the risk of paravalvular leakage and bleeding. Bypass of the mitral valve with a valved conduit is another option for the treatment of severe calcific mitral stenosis [93].

Bioprosthetic valves are generally recommended for patients > 65 years and there is also greater usage in younger patients due to lack of necessity of chronic anticoagulation. The Ross operation (replacement of aortic valve with a pulmonary autograft and replacement of the pulmonary valve with a homograft) is an alternate for adolescents, young adults, including woman who wish to become pregnant and it is not favored by the majority of surgeons due to complexity of the procedure, but excellent outcomes occurred in centers with expertise in this procedure [94].

### Screening of population

Aortic valve calcification extending to anterior mitral leaflet with severe aortic stenosis was shown in Figures 9 to Figure 32. A bicuspid aortic valve calcification with rheumatic mitral stenosis was shown in Figures 17, 18, 23, 24 and it is ‘mushroom’ shaped [95] as in Figure 25 in a 34-year-old male. J-shaped mitral-aortic calcification was shown in Figure 7 in a 52-year-old male. Dense calcification of anterior mitral leaflet was shown in Figure 29 and aortic valve calcification resembling ‘calcified amorphous tumor’ as in Figure 31 in a

60-year-old male. Calcification of aortic valve in Endomyocardial fibrosis with rheumatic mitral stenosis was shown in Figures 27, 28 in a 58-year-old male. Calcification of mitral-aortic membrane was shown in Figure 30 in a 60-year-old male and in one-year old child as in Figure 32.



Figure 9. Subcostal view showing the rheumatic thickening of mitral valve and LA Dilatation.

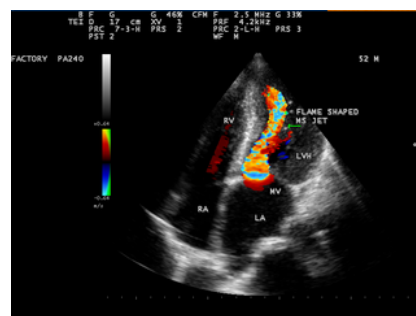


Figure 10. Apical view showing the ‘flame-shaped’ mitral stenosis jet in a 52-year-old male.

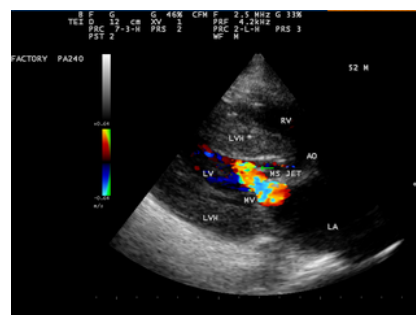


Figure 11. Subcostal view showing the mitral stenosis jet.

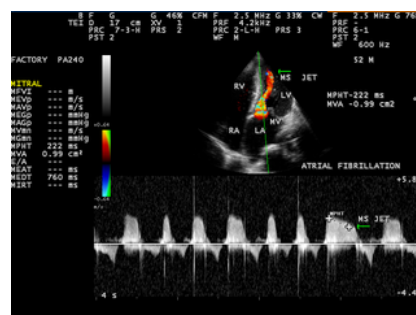
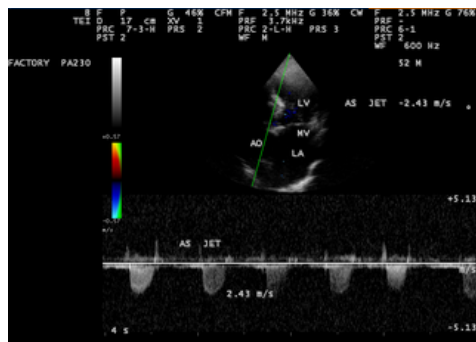
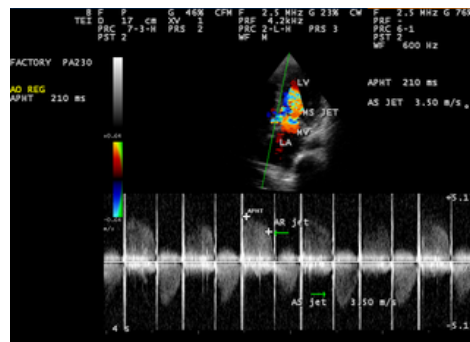


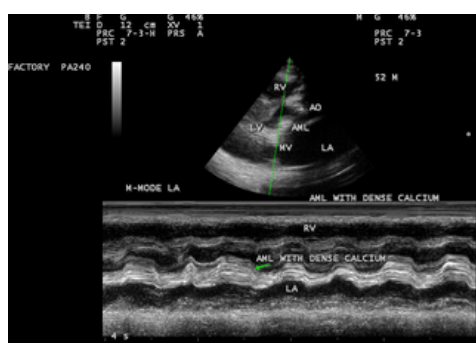
Figure 12. CW (continuous wave) Doppler showing the severe mitral stenosis.



**Figure 13.** CW (continuous wave) Doppler showing the aortic stenosis jet in a 52-year-old male.



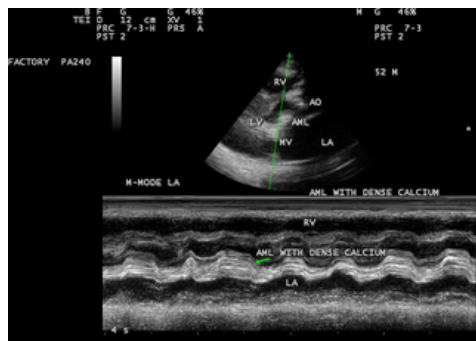
**Figure 17.** CW (continuous wave) Doppler showing the jets of aortic stenosis and regurgitation in a 34-year-old male.



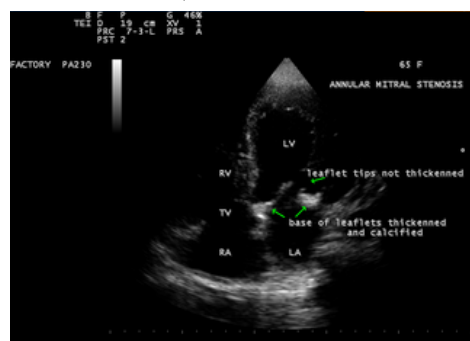
**Figure 14.** M-mode LV study showing the high ejection fraction (87%).



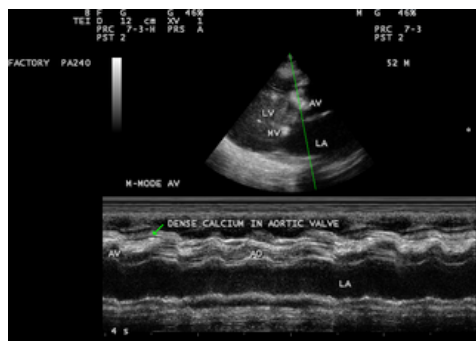
**Figure 18.** Apical view showing the rheumatic mitral valve in a 34-year-old male (Rheumatic mitral stenosis).



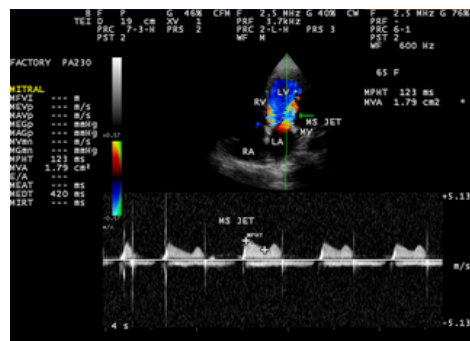
**Figure 15.** M-mode at AML showing the dense calcium in a 52-year-old male.



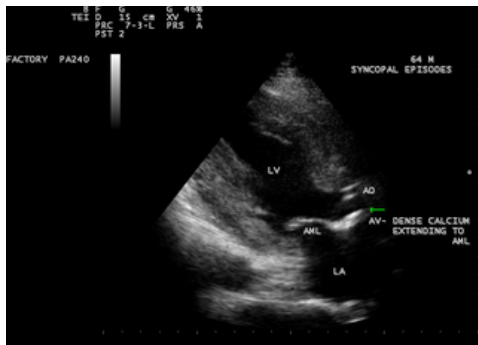
**Figure 19.** Apical view showing the annular mitral stenosis with basal leaflet calcification in a 65-year-old female.



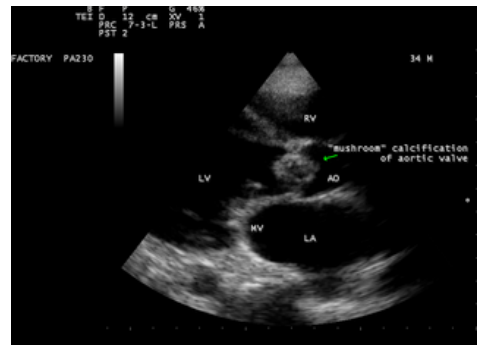
**Figure 16.** M-mode at aortic valve showing the dense calcium in a 52-year-old male.



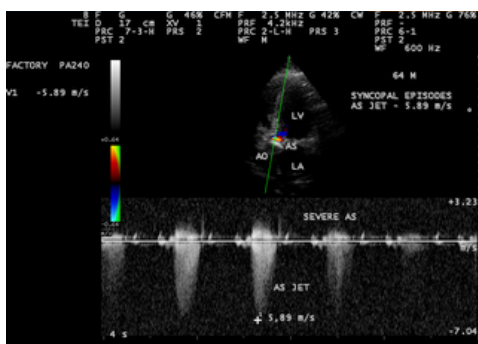
**Figure 20.** CW (continuous wave) Doppler showing the annular mitral stenosis (mild) jet in a 65-year-old female.



**Figure 21.**Parasternal long axis view showing the extension of aortic valve calcification to anterior mitral leaflet in a 64-year-old male.



**Figure 25.**"Mushroom" shaped calcification of Bicuspid aortic valve in a 34-year-old male.



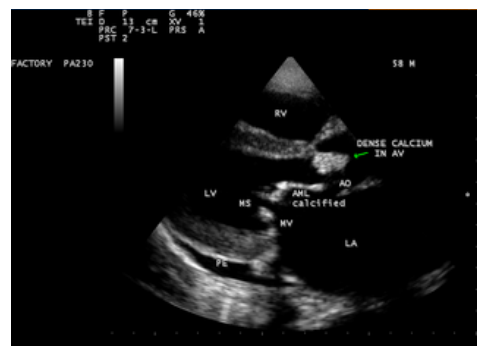
**Figure 22.**CW (continuous wave) Doppler showing the severe aortic stenosis jet in a 64-year-old male.



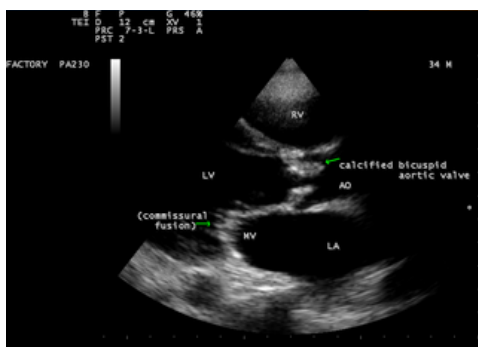
**Figure 26.**Short axis view showing the dense bicuspid aortic valve calcification in 34-year-old male.



**Figure 23.**Parasternal long axis view showing dense calcium in aortic valve and anterior mitral leaflet in a 34-year-old male.



**Figure 27.**Parasternal long axis view showing the dense calcium in aortic valve and anterior mitral leaflet in EMF (endomyocardial fibrosis) in a 58-year-old male.



**Figure 24.**Parasternal long axis view showing the 'mushroom' calcification of bicuspid aortic valve in 34-year-old male.

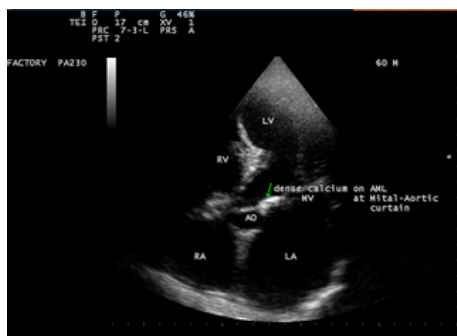


**Figure 28.**Apical view showing the calcification of anterior mitral leaflet and RV apical fibrosis suggesting EMF (endomyocardial fibrosis) and rheumatic mitral stenosis in a 58-year-old male.

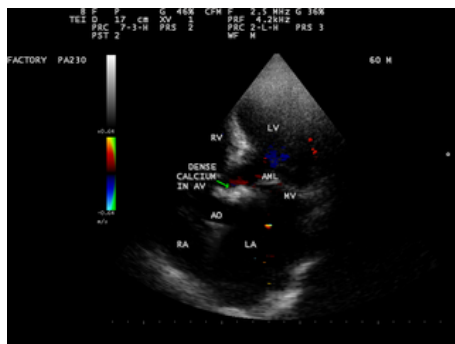




**Figure 29.**Parasternal long axis view showing the calcification of anterior mitral leaflet in a 60-year-old male.



**Figure 30.**Showing the dense calcium in mitral-aortic membrane in a 60-year-old male.



**Figure 31.**Dense calcium in aortic valve mimicking as 'calcific amorphous tumor' in a 60-year-old male.



**Figure 32.**Rheumatic calcification of mitral-aortic membrane in a one-year-old female child.

## Conclusions

Analyses revealed a distinct accumulation of calcium in aortic valve tissues and future research should address mineralization in earlier disease stages, exploring additional trace elements and molecular contributors to develop biomarkers and therapeutic preventions to alleviate this disease process at its onset. The chemical and phase composition of pathogenic minerals formed on human heart valves (cardiolites) has been studied. It is shown that cardiolites are organ mineral aggregates, whose mineral component is represented by nonstoichiometric carbonate-containing hydroxyl apatites with a variable Ca/P atomic ratio. Structural damage and mineralization in aortic valve tissue, with chronic wood smoke exposure emerging as a potential causative factor. Environmental factors, such as wood smoke that emits harmful and carcinogenic pollutants, carbon monoxide (CO), and nitrogen oxide (NOx), as well as other reactive compounds. FESEM images of MVs showed the presence of minerals on their surface, thus providing evidence on their possible role in the pathophysiology of mineralization. Decellularization of bovine pericardium using surfactants like deoxycholic acid, followed by aldehyde neutralization with sodium bisulfite and preservation in glycerol, effectively prevent calcification in bioprosthetic valves. Advances in nanotechnology and tissue engineering may provide better options for mitigating prosthetic heart valve calcification in the future. Polymeric heart valves (PHVs) are designed to overcome the drawbacks of current prostheses by eliminating animal-derived proteins and reducing the risk of calcification and immune response. Emerging technologies, such as 3D bioprinting, hold the potential to produce custom-made valves with mechanical properties tailored for dynamic biological environments. The CorTricuspid valve technology utilizes the decellularization approach and is designed to be implanted and progressively colonized by the patient's own cells (mainly blood progenitor cells), which will further grow and differentiate into valvular interstitial cells and eventually form a totally regenerated valve.

## Disclosure Statement

No potential conflict of interest was reported by the authors.

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