Viewing cancer pathophysiology as a lead in understanding cardiac and vascular disease mechanisms

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Abstract
This article describes how understanding mechanisms used by cancer cells—both prosurvival (oncogenic) and pro-apoptotic (tumour suppression)—sheds light on important ‘cues’ for prosurvival and apoptotic pathways employed in the cardiac and vascular system. Commencing with the mevalonate pathway, numerous examples are presented whereby cancer oftentimes foretells an understanding of relevant mechanisms for cardiology. Pathologies such as cardiomyopathies including heart failure, hypertension/vascular dysfunction, and reaction to ischaemic-reperfusion injury are discussed. Key features emerge in terms of homeostasis within the cardiac and vascular system and the observation that cardiac pathologies do not present in mere isolation but as co-morbidities. Mechanisms resulting in such pathologies are revealed by considering prosurvival versus pro-apoptotic imbalance (homeostatic disturbance). Overall, one may gain an improved foreknowledge of such mechanisms behind these important regulatory paths in cardiology from studying cancer molecular mechanisms.

Keywords: Apoptosis, atheroma, cancer, cardiomyopathy, cardioprotection, farnesol, heart failure, hypertension, mevalonate pathway, oncogene, prosurvival factor, tumour suppressor, vascular disease

Introduction
Recently [1], it was emphasized that cardioprotective mechanisms/factors targeting ischemia/reperfusion (I/R) injury are of pivotal significance and form a “foremost experimental goal”—a ‘holy grail’ of cardiac and vascular medicine. A model has already been proposed emphasizing that cancer may play a central role for elucidating and indeed forecasting such factors and mechanisms [2]. In that analysis it has been notably demonstrated that cancer and heart tissue react similarly at the molecular level to withstand imposed environmental challenge. In regards this relation, it was stated: “As another feature of the model, ways to better forecast future therapies aimed at augmenting cardioprotective paths is made possible through understanding of pathways used to sustain cancer cells under external challenges.” [2]. In effect, this model represents: “…a novel and important ‘cross road’ between physiology and pathology” [2].

Importantly, not only do prosurvival/cytoprotective pathways match between heart and cancer but also mechanisms relating to tumour suppression/apoptosis and cardiomyocyte damage [2]. Therefore overall, by looking at the cancer prosurvival model ‘in reverse’ one has a means to better understand and ultimately aid in developing targeted therapeutics for heart/vascular diseases. Along this line, it has been further detailed the notion that cancer may forecast factors in respect to cardioprotection [3]. In this regard, cancer prosurvival factors claudin, CASPR3, CDC42-binding protein kinase beta and dihydropyrimidinase-related protein 2 (CRMP2) have not been examined in the heart for their relation to cytoprotection. As such, there remains much scope for productive investigation based on cancer for dissecting target factors involved in heart diseases.

This relation between cancer and the heart has been extended from the prosurvival model [2] to show that cancer biomarkers match with those for cardioprotection—a useful tool for cardiology risk assessment [4]. As a follow on from the cancer prosurvival model, cancer survival factors match with hypertension, cardiohypertrophy and atheroma molecular markers. An upset in homeostasis towards progrowth cellular programming may be adverse for the cardiac/vascular system [5].

The purpose of this article is to emphasize and extend the key and recurring message that cancer prosurvival and apoptotic pathways/mechanisms mimic and oftentimes anticipate such
shared pathways of note within the cardiac and vascular system. Appreciating this shall aid in revealing deficiencies in understanding cardioprotection and heart and vascular diseases in general. Assisting with providing valuable ‘cues’ for therapies in cardiac and vascular medicine is a central aim of connecting heart-cancer molecular and cell biology mechanisms.

Methodology

A literature search was performed using the PubMed database through use of key words joined via the Boolean operator ‘and’ as I have detailed recently [6]. The means of producing novel concepts by bridging seemingly unrelated knowledge fields is known as ‘literature-based discovery’ (LBD). LBD is based on the hypothesis that two islands/strands of knowledge (concepts) A and C may be related to each other if they share a link to an intermediate concept B (the greater the number of shared links between A and C, the more probable is the relationship between them). This notion is known as Swanson’s ‘ABC’ model [7] and I use this approach to bring to light the productive connection between cancer (concept A) and the cardiac and vascular system (concept C) via shared prosurvival/apoptotic molecular mechanisms/factors (concept B).

Literature searches employed the following phrases: cancer/cancer therapy resistance and factor (where the factor is either a prosurvival/oncogene or tumour suppressor); cardioprotection/cardiomyocyte cytoprotection and factor; myocardial ischaemia and factor. Other substituted key terms were hypertension, cardiomyopathy/hypertrophy, heart failure, vascular dysfunction/atheroma. Such searches revealed when the particular factor(s) of interest were initially associated with cancer or heart disease. Mechanistic pathways were explored from the cardiac/vascular context in cancer to determine correlations and timing of discovery to highlight the relationship of cancer signaling pathways and relevance to cardioprotection, cardiac hypertrophy, hypertension, atheroma and heart failure.

Results and discussion

For ease of presentation, various aspects of the cardiac and vascular system and pathologies are individually highlighted. The ‘logic trail’ running throughout is aimed to show that cancer provides an adequate resource to appreciate these aspects from a mechanistic and, following on from this, therapeutics standpoint.

Cardioprotection against ischaemia-reperfusion challenge

In regards the mevalonate pathway [1], it is interesting to note that farnesol is depicted as cardioprotective via a novel protein geranylgeranylation (prenylation) mechanism. It was further indicated that G-proteins, including members of Ras superfamily, are involved in signal transduction of I/R injury and cardioprotection, although their prenylation status has not been examined in this context [1]. My proposition is that prenylation – a post-translational modification – is central in cardioprotection and protein targets are predicted and indeed, defined, through examining cancer. Such cancer prosurvival lipid metabolic pathway mechanisms [8] are closely paralleled in the heart. Notably, consistent with this proposition, by inhibiting lipid metabolic paths, particularly the mevalonate pathway, anti-cancer therapeutics are enhanced [8]. Further, in cancer, prosurvival prenylation reactions have been earlier considered to be suited targets for therapies [9]. Inhibiting protein geranylgeranylation and glycosylation (mediated by Dolichol), prosurvival end-products of the mevalonate pathway [1], by lovastatin inhibits erythropoietin-related cell proliferation in cancer [10]. Predictably, interfering with the Dolichol pathway as seen in dolichol kinase deficiency, leads to heart damage - dilated cardiomyopathy [11].

Farnesol demonstrates a ‘U’ shaped survival profile in cardio-myocytes, being toxic at higher doses [1]. This factor directs protein prenylation reactions and has a role in Ras activation via prenylation, certainly a key process in cancer [12]. At high concentrations, farnesol appears also toxic in cancer and mechanistically, the toxicity connects with NF-kappa B and MEK1/2-ERK1/2 pathway and endoplasmic reticulum [13]. Overall, a number of these farnesol-related aspects align between cancer and heart - cancer providing a lead or ‘cue’ for further investigation in the heart context.

Other intriguing parallels are noted. Earlier, manumycin, a farnesylsination inhibitor, was proven effective in targeting cancer [14]. Later, urocortin-II cardioprotection was seen to be abolished by manumycin [15] implicating similar mechanism and forecast by cancer. Further, it has been stated that activation of JNK via Rac1 leads to cardiomyocyte cytoprotection [1]. Earlier, the involvement of Rac1 and JNK in oncogenesis was proven [16]. RhoA is cardioprotective [1] and acts via an ‘unexpected’ role for PKD as a downstream mediator [17]. Earlier in cancer [18], both RhoA and PKD were found to have joint key roles in oncogenesis–thus anticipating the role of PKD in RhoA-mediated cardioprotection.

Numerous other instances exemplify the utility of cancer as a lead in cardioprotection pathway discovery. G-protein-coupled receptors, such as Adenosine A1 receptor, employ adenosine as a key ligand in stimulating cardioprotection [19]. Inhibition of this adenosine receptor is proposed for cancer therapeutics consistent with its prosurvival capacity. Very recently, [20], the Adenosine A1 receptor agonist 2-Cl-IB-MECA was shown to mediate cardioprotection via what the authors of that work considered as a novel mechanism involving MEK1/2 (elucidated from targeted U0126 inhibition) and PI3K/Akt. Earlier, [21], adenosine, through A1 receptor, mediated a proliferative/prosurvival effect on colon cancer cells. Notably, U0126 blocked the agonist 2-Cl-IB-MECA induced proliferation - this novel mechanism for the heart being neatly foretold by cancer. Further, the G-protein- coupled opioid receptor forms a notable example. The kappa opioid receptor...
is involved in directing cardiomyocyte cytoprotection [22]. Unsurprisingly, kappa opioid receptors align with oesophageal carcinoma progression [23].

As further examples, A1/Bfl-1, a Bcl-2 family member, is stimulated by prosurvival NF-kappa B to prevent apoptotic release of mitochondrial cytochrome c thus providing resistance to chemotherapy induced apoptosis [24]. Prosurvival Bfl-1 is expressed in coronary smooth muscle cells on glucose stimulation in diabetes and may represent an adverse mechanism in the vasculature [25]. Later, in the heart itself, Bfl-1 was noted as a potent cardioprotective factor [26]. In preconditioning cardioprotection, prosurvival Mcl-1 – also a Bcl-2 member - acts in a mechanism with STAT3 and NF-kappa B [27]. In the process of oncogenesis this mechanism is mimicked on upregulation of Mcl-1 with NF-kappa B and STAT3 [28].

In various energy/metabolic-related aspects, cancer and heart align, as I have previously highlighted [2]. Inhibiting cardiac palmitoyltransferase I (CPT-1), thus targeting fatty acid oxidation, decreases I/R tolerance in the disease-free animal model context [29]. In cancer, [30], CPT-1 forms a convenient, efficient ATP production system via beta-oxidation of fatty acids for metabolically active and needy cancer cells. As such, it forms a prosurvival mechanism much like CPT forms a survival path in the context of the disease-free heart [29]. Notably earlier, [31], inhibiting CPT-1 in cancer cells led to apoptosis via increasing ceramide and BNI3 levels. These mechanisms involving CPT have not as yet been explored in the heart and taking the ‘cue’ from cancer, it may be anticipated that a similar pathway may apply for cardio-myocyte metabolic damage.

Like prenylation [1], S-nitrosylation forms a post translational cardioprotective mechanism. Atorvastatin induces cardioprotection and is infarct sparing via iNOS/Cox-2 - iNOS producing NO which in turn activates prosurvival Cox-2 via S-nitrosylation [32] (see Table 5—below). The importance of the involvement of iNOS/Cox-2/S-nitrosylation mechanism is recapitulated in cancer [33]. In this scenario, iNOS/NO increases activity of Cox-2 and leads to chemoresistance. Further, iNOS/NO activate EGFR/Src via S-nitrosylation influencing oncgene prosurvival network: Myc/Akt/STAT3. Such prosurvival machinery and mechanisms in regard S-nitrosylation remain to be explored in detail for the heart - the ‘cue’ here for investigation comes from cancer.

Cardioprotection is afforded by NO both via S-nitrosylation as well as via the cGMP/PKG pathway [34]. Not unexpectedly, cancer also uses the NO/cGMP/PKG machinery as a prosurvival mechanism [35].

Ion channels represent a further convincing presentation for the relation of cancer factors to heart disease. The cystic fibrosis transmembrane conductance regulator (CFTR) chloride anion channel maintains a central role in cardioprotection [36], yet earlier was considered as a prosurvival target for cancer therapy [37]. Cardioprotection may be also related to cationic channels such as K(ATP) [38]. In parallel, this cation channel aligns with cancer prosurvival [39] where K(ATP) blockers inhibit cancer cell proliferation.

In short, lipid and general metabolic paths, mitochondrial mechanisms as well as receptor pathways for opioids and cardio-active factors such as adenosine to name a few, all funnel towards demonstrating a close mechanistic cancer-heart alignment (Table 1). Therefore this understanding has clear clinical implications in regards appreciating and indeed foretelling cardioprotection against I/R injury.

Table 1. Alignment of mechanisms/factors relating cancer to ischaemic cardioprotection.

<table>
<thead>
<tr>
<th>Cancer</th>
<th>Cardioprotection</th>
</tr>
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<tbody>
<tr>
<td>Prenylation (Farnesol) a</td>
<td>Prenylation (Farnesol) a</td>
</tr>
<tr>
<td>Glycosylation (Dolichol) b</td>
<td>Glycosylation (Dolichol) b</td>
</tr>
<tr>
<td>Farnesylation (Manumycin) c</td>
<td>Farnesylation (Manumycin) c</td>
</tr>
<tr>
<td>Rac/JNK d</td>
<td>Rac/JNK d</td>
</tr>
<tr>
<td>RhoA/PKD e</td>
<td>RhoA/PKD e</td>
</tr>
<tr>
<td>Adenosine A3 receptor/MEK1/2 f</td>
<td>Adenosine A3 receptor/MEK1/2 f</td>
</tr>
<tr>
<td>kappa-opioid receptor g</td>
<td>kappa-opioid receptor g</td>
</tr>
<tr>
<td>A1-Bfl1 h</td>
<td>Bfl1 h</td>
</tr>
<tr>
<td>Mcl1/NF-kappa B/STAT3 i</td>
<td>Mcl1/NF-kappa B/STAT3 i</td>
</tr>
<tr>
<td>Carnitine palmitoyl-transferase l j</td>
<td>Carnitine palmitoyl-transferase l j</td>
</tr>
<tr>
<td>Nitric oxide/cGMP/PKG k</td>
<td>Nitric oxide/cGMP/PKG k</td>
</tr>
<tr>
<td>S-nitrosylation/Cox-2/iNOS/ nitric oxide l m</td>
<td>S-nitrosylation/Cox-2/iNOS/ nitric oxide l m</td>
</tr>
<tr>
<td>Anion channel: CFTR m</td>
<td>Anion channel: CFTR m</td>
</tr>
<tr>
<td>Cation channel: K(ATP) n o</td>
<td>Cation channel: K(ATP) n o</td>
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</table>

aPrenylation (the addition of hydrophobic moiety to a protein to assist in cell membrane attachment) is a cancer prosurvival mechanism [8,9] and is a suggested mechanism that may lead also to ischaemic cardioprotection [1] with farnesol being an active component of this process.

bDolichol, a product of the mevalonate pathway, mediates glycosylation, a cancer prosurvival mechanism [10] and assists in sustaining myocardial integrity [11].

cFarnesylation (prenylation by means of addition of an isoprenyl group) inhibition by manumycin targets cancer [14] and abolishes urocortin-II mediated cardioprotection [15].

dRac1-JNK prosurvival cascade is involved in cancer pathophysiology [16] and is also considered to be involved in cardioprotection [1].

eRhoA-PKD cascade is a prosurvival feature in cancer [18] as well as in cardioprotection [1,17].

fAdenosine A3 receptor controls a prosurvival response in cancer [21] involving MEK1/2 and also mediates cardioprotection via the same mechanism [20].

gkappa-opioid receptor aligns with cancer [23] and cardioprotection [22].
hBfl1 (A1-Bfl1) is a prosurvival factor in cancer [24] and prosurvival in the vascular system in the context of diabetes [25] and directly cardiomyocyte cytoprotective [26].
iCancer employs the prosurvival cascade Mcl1/NF-kappa B/STAT3 [28] with the same cascade operating in cardioprotection [27].
Addressing heart failure

Not only do prosurvival but also pro-apoptotic cardiac/vascular mechanisms mechanistically align with cancer [2]. This has significance in heart failure for which biomarkers and mechanisms are highly sought after. For example, dipeptidyl peptidase IV (DPP IV) was found to act via SDF-1 modulation as a tumour suppressor [40]. Mechanistically, SDF-1, as down-regulated by DPP IV, was exposed as a regulated prosurvival pathway in cancer [40]. Another prior study, [41] indicated that sanguinarine, a plant derivative, relates to suspected precancerous alterations. This agent is a natural DPP IV inhibitor and assists in explaining a potential oncogenic mechanism [42]. I consider that as a follow-on, sanguinarine is cardioprotective by augmenting SDF levels secondary to DPP IV inhibition.

In heart failure, SDF is beneficial consistent with its prosurvival role [43]. Recently, remote ischaemic preconditioning has been demonstrated to relate to humoral production of SDF-1 with serum levels of DPP IV downregulating this factor [44]. Circulating DPP IV aligns with cardiac dysfunction in heart failure and thus is a suited biomarker and target for same. Such key observations were predicted in cancer from an anti-survival viewpoint (Table 2).

Addressing hypertension and atheroma

As anticipated, tumour suppression as an anti-survival mechanism counters hypertension which represents, to a significant degree, a vascular smooth muscle progrowth imbalance. Induction of senescence via Nutlin-3a prevents ubiquitin ligase MDM2, a negative regulator, from interacting with the long established tumour suppressor p53, thus leading to inhibition of proliferation of pulmonary arterial smooth muscle cells [45]. Another well equally established tumour suppressor, PTEN, on upregulation via PPARgamma agonist leads to hypoxic apoptosis of pulmonary arterial vascular smooth muscle cells and provides a recent rationale for therapeutics to target pulmonary hypertension [46]. Table 2 summarizes several of these mechanistically shared aspects between cancer and vascular dysregulation seen in hypertension.

Notably, a number of factors, viz: angiotensin II, interleukin-6, endothelin, sphingosine-1-phosphate, chromogranin, enolase and VEGF [4,5] relate to cardiocytoprotection and cancer. Any imbalance in expression of these progrowth factors may promote hypertension and vascular dysfunction/atheroma [4,5]. Interestingly, in regards the latter factor, VEGF, prosurvival factor NF-kappa B was found to be involved in a novel mechanism regulating VEGF-related stretch-induced cardiac hypertrophy [47]. Here it was stated that: ‘Elucidation of this novel mechanism may provide a target for developing future pharmacotherapy to treat hypertension and heart disease.’ Notably, the VEGF and linked NF-kappa B prosurvival mechanism was foreshadowed in therapy resistant, relapsing cancer (Table 2). Unsurprisingly, statin treatment, via RhoA prenylation inhibition, induces vascular smooth muscle cell apoptosis thus opening a further therapeutic window for hypertension and atheroma management [49] (see Table 5—below). This also aligns with the cancer mechanism [50]. In apoE(-/-) mice which were provided with a Western-type diet, atherosclerotic lesions readily formed [51]. Simvastatin led to an up-regulation of Bcl-2 and Bcl-xL expression which are classical cancer oncogenes and decreased tumour suppressor p53 expression. This statin may therefore be said to prevent apoptosis in the labile atherosclerotic plaque thus potentially leading to plaque stabilization (see Table 5—below). Importantly, this recently uncovered statin-related interplay of established cancer prosurvival/pro-apoptotic factors in the context of atheroma is reflective of the value of comparison of cancer

Table 2. Alignment of mechanisms/factors relating cancer to cardiac failure, hypertension and atheroma.

<table>
<thead>
<tr>
<th>Cancer</th>
<th>Cardiac failure, hypertension, atheroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPPIV/SDF</td>
<td>DPPIV/SDF–heart failure&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>p53</td>
<td>p53–pulmonary hypertension&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>PTEN</td>
<td>PTEN–pulmonary hypertension&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>VEGF/NF-kappa B&lt;sup&gt;d&lt;/sup&gt;</td>
<td>VEGF/NF-kappa B–hypertension&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Interleukin-6</td>
<td>Prosurvival/progrowth factors–atheroma/hypertension&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chromogranin</td>
<td></td>
</tr>
<tr>
<td>Enolase</td>
<td></td>
</tr>
<tr>
<td>Endothelin</td>
<td></td>
</tr>
<tr>
<td>Sphingosine-1-phosphate</td>
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</tbody>
</table>

<sup>a</sup>Prosurvival SDF (stromal cell-derived factor) levels are regulated in cancer by tumour suppressor DPP IV (dipeptidyl peptidase IV) [40], and in heart failure SDF being prosurvival is beneficial [43] with DPP IV opposing this via SDF degradation.

<sup>b</sup>Tumour suppressor, p53, is involved in inhibition of pulmonary arterial smooth muscle cell growth thus targeting pulmonary hypertension [45].

<sup>c</sup>Tumour suppressor, PTEN, is also involved in inhibiting pulmonary arterial smooth muscle cell growth and targets pulmonary hypertension [46].

<sup>d</sup>Prosurvival cancer VEGF/NF-kappa B axis [48] has been considered a target for hypertension [47].

<sup>e</sup>In addition to their cardiocytoprotective role [4,5], progrowth factors align with hypertension and atheroma formation–reflecting vascular dysfunction.
mechanisms to the cardiac/vascular context.

Overall, in terms of clinical relevance, therapeutics that shall either promote tumour suppression (anti-growth) or agents that target excessively produced progrowth, proinflammatory factors, may well be able to address hypertension and atheroma (Table 2). The treatment puzzle is made complex by the fact that progrowth factors are in themselves cardioprotective and anti-growth mechanisms may promote cardiac damage and lead to exacerbating heart failure. To aid addressing this, I have already stated the importance for maintaining a balance or homeostasis in regards prosurvival vs pro-apoptotic factors as the key message for clinicians [5].

Addressing cardiac hypertrophy

In cardiac hypertrophy one would anticipate that prosurvival pathways are unbalanced in favour of excessive progrowth stimuli. Notably, statins target cardiac hypertrophy via inhibition of RhoA geranylgeranylation/preylation and membrane localization [52] (see Table 5 below). This neatly aligns with the mechanism for statin targeting RhoA in cancer [50].

Hypertrophic-related Ras is pro-growth in the heart and its balancing tumour suppressor, RASSF1A, downregulates the Ras-Raf1-Erk1/2 cardiac circuit – truly a case of ‘where the heart and cancer meet’ [2,53]. It was observed that the relationship between signal paths controlling tumour growth and cardiac hypertrophy (viz: proto-oncogenes positively impacting on the development of hypertrophy) is of very significant interest and importance [53]. Thus appreciating the precise mechanisms involved is key and notably pro-apoptotic factors such as tumour suppressors maintain a balance in regulating hypertrophic signaling and form tangible therapeutic targets for cardiac hypertrophy.

KCNQ1 is a potassium channel protein and aids in cardiomyocyte repolarisation. Already in cancer, it is seen that low expression of KCNQ1 is associated with poor survival and this channel factor is thus classified as a tumour suppressor [54]. Recently [55], in a model for cardiac hypertrophy, a major reduction in expression of KCNQ1 is evident. This is consistent with KCNQ1 as a growth inhibitor antagonizing excessive prosurvival stimulus in the heart. This factor thus forms part of growth control-homeostatic balance-as forecast from cancer. A summary of these relationships is presented in Table 3.

Addressing co-morbidities

Cardiac and vascular diseases oftentimes present as co-morbid conditions. For example, hypertension with cardiac hypertrophy share an imbalance of progrowth mechanisms that cancer also displays (above). Shared pro-apoptotic, anti-survival mechanisms, may explain, for example, such co-morbid features as heart failure with aneurysm formation. In this scenario, the transcriptional regulator Kruppel-like factor 15 (Klf15) levels are markedly reduced in heart failure and aortic aneurysm [56]. In Klf15 deficient animal models these co-morbid pathologies develop in a p53-dependent and p300 acetyltransferase-dependent manner. Activation of KLF15 inhibits p300-mediated acetylation of p53 and deficiency of prosurvival Klf15 produces hyperacetylation of p53 in heart and aorta. Importantly, p300-mediated p53 acetylation is proving to be a key post-translational modification for p53 function and is reduced by MDM2 inhibitor [57]. Thus there is a molecular commonality between these co-morbidities that rests on a balance between prosurvival/apoptotic regulation via Klf15. Recently, vascular smooth muscle cell apoptosis in aneurysms was related to MDM2 inhibitor reduction with resultant increase in p53 activity [58]. This is reminiscent of MDM2 involvement in regulating p53 in the context of proliferation of pulmonary arterial smooth muscle [45].

Unsurprisingly, this balance in prosurvival/apoptosis has been mechanistically reflected within the context of cancer, where Kruppel-like factor (Klf6) silencing resulted in p53 upregulation and apoptosis in hepatic carcinoma cells [59]. Clearly, the Kruppel-like factor balance of prosurvival/apoptosis in the cardiac/vascular system is closely mimicked and forecast via cancer.

Not only are co-morbid features recognized within the cardiac and vascular system but also it must be recalled that cardiovascular diseases are not isolated in their context—they often-times present concurrently alongside metabolic disturbances such as insulin resistance and obesity. Proinflammatory factors such as adipocytokines and oncoproteins/prosurvival factors in concert support cardiac hypertrophy and upset homeostatic balance to favour hypertension/atheroma (above). Examples are interleukin-6 and TNFalpha [5]. Further, as TNF and interleukin-6 relate to atheroma, hypertension and cardiomyopathies, this may be considered an overall excessive ‘prosurvival’ reaction. These are feature hallmarks of obesity-associated diabetes with the metabolic syndrome. In addition, DPP4, a cancer tumour suppressor and agent countering cardioprotection (above) and playing a role in heart failure is itself an adipocytokine [60]. This shines a clearer light on the link between obesity/metabolic disease and potentially

Table 3. Alignment of mechanisms/factors relating cancer and cardiac hypertrophy.

<table>
<thead>
<tr>
<th>Cancer</th>
<th>Cardiac hypertrophy</th>
</tr>
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<tbody>
<tr>
<td>RhoA prenylationa</td>
<td>RhoA prenylationa</td>
</tr>
<tr>
<td>Ras/RASSF1A</td>
<td>RASSF1A/Rasb</td>
</tr>
<tr>
<td>KCNQ1</td>
<td>KCNQ1</td>
</tr>
</tbody>
</table>

aRhoA prenylation is a post-translational prosurvival pathway in cancer [50]–the same mechanism is present in cardiac hypertrophy [52].
bRas is a noted prosurvival path in cancer and is balanced by its tumour suppressor, RASSF1A [53] with the same mechanism applying in the heart regulating cardiac hypertrophy [53].
cKCNQ1 (a potassium channel factor) is a tumour suppressor [54] and is lowered in cardiac hypertrophy [55].
damaging consequences this has on the cardiovascular system. Thus both prosurvival and pro-apoptotic pathways are involved that mimic the cancer context. An overall summary is given in Table 4.

Table 4. Mechanisms/factors including inflammation relating cancer to cardiac-vascular diseases and co-morbidities.

<table>
<thead>
<tr>
<th>Cancer</th>
<th>Cardiac-vascular diseases/Co-morbidities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kruppel-like factor/p53(^a)</td>
<td>Kruppel-like factor/p53-heart failure/aneurysm(^a)</td>
</tr>
<tr>
<td>Adiponectin-IL-6/TNF(^b)</td>
<td>IL-6/TNF-cardiomyopathy/hypertension/atheroma/insulin resistance/obesity(^b)</td>
</tr>
<tr>
<td>Adiponectin-DPPIV(^c)</td>
<td>DPPIV-heart failure(^c)</td>
</tr>
<tr>
<td>Inflammation: NF-kappaB/oX-LDL-LOX(^d)</td>
<td>Inflammation: NF-kappaB/oX-LDL-LOX1-atheroma(^d)</td>
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</table>

\(^a\)Kruppel-like factor, family member Klfl, downregulates p53 tumour suppressor in the cancer context, thereby providing a prosurvival signal [59]—Kruppel-like factor, family member Klfl1, inhibits p53 activation and deficiency of this factor relates to co-morbid development of heart failure with aneurysm [56].

\(^b\)Proinflammatory cytokines, such as adiponectin interleukin-6 and TNF from adipose tissue, may favour a progrowth response (the latter via NF-kappaB activation) relevant in the cancer context and evident in cardiomyopathy/hypertension/atheroma [5] alongside being related to co-morbid features such as obesity/insulin resistance.

\(^c\)Adiponectin DPPIV is a tumour suppressor and counter cardio-protection [60].

\(^d\)Inflammation forms a notable mechanistic commonality between cancer and cardiovascular disease, as exemplified by oX-LDL and its receptor LOX-1 activating the NF-kappaB inflammatory cascade which in turn promotes cancer and atheroma/vascular dysfunction [62].

Addressing inflammation—a common link between cancer and heart diseases

As I have detailed [5,6], inflammation is a major mechanistic common linkage between many conditions such as atheroma/vascular disease, cardiac disease, cancer and neurological disease. Obesity and diabetes, important co-morbidities of cardiac and vascular diseases, are related to ‘metinflammation,’ or metabolic inflammation, resulting in insulin resistance [61].

Targeting inflammatory response \(\text{via}\) modulating the NF-kappaB signaling axis—a central player—by such newly ‘repurposed’ immune modulatory agents as Amlexanox may hold significant promise for a multitude of inflammatory-related conditions such as atheroma [6]. Interestingly, the link between cancer and inflammation, and NF-kappaB and atheroma has been strongly underlined with oX-LDL and its receptor LOX-1 [62]. This ligand-receptor complex activates the inflammatory pathway through NF-kappaB leading to cell transformation. LOX-1 maintains the transformed state in a diverse range of cancers and supports tumor growth. Upregulation of LOX-1 by oX-LDL is connected to endothelial cell dysfunction, smooth muscle cell growth and migration seen in atheroma and these are all matching features of the tumourigenic phenotype. It was stated: ‘As in atherosclerosis, oX-LDL and its receptor LOX-1 activate the inflammatory pathway through nuclear factor-kappaB, leading to cell transformation’ [62] (Table 4). This leaves no doubt in respecting the tight relation between cancer and vascular disease—a theme that I have portrayed in extending to cardiac and vascular diseases generally (Figure 1).

Addressing therapeutics

One of the central aspects arising from the close relation between...
heart and cancer prosurvival and apoptotic mechanisms is the fact that agents targeting cancer shall have a detrimental effect on cardiomyocyte physiology [2]. This defines the relatively new field of cardio-oncology [63]. Recently, it was indicated that human epidermal growth factor receptor-2 (HER2) signaling is prosurvival not only in mammary gland carcinoma but also is a matching prosurvival mechanism in cardiomyocytes [64]. Thus, toxicity towards the heart is certainly a negative issue in terms of employing HER2 targeted therapeutics for cancer. Means to optimize such anti-cancer therapeutics were considered through screening against induced pluripotent stem cells in an attempt to idealize cancer therapy selection on an individual patient (personalised medicine) basis [64].

The relation of statins to mechanisms involved in cancer may be usefully adapted for cardiac and vascular disease therapeutics—a theme pursued throughout this article. For example, Atorvastatin induces cardioprotection and is infarct-sparing via cancer mechanisms [32]. Further, statin therapy may, via RhoA prenylation inhibition, a cancer therapeutic target, result in vascular smooth muscle cell programmed cell death, thence delivering prospective therapeutics for vascular diseases such as hypertension [49]. Simvastatin, by increasing expression of Bcl-2 and Bcl-xL prosurvival oncogenic factors, and diminishing levels of tumour suppressor p53 expression, targets labile atherosclerotic plaques leading to plaque stabilization [51]. In respect to cardiac hypertrophy, statin therapy via targeted inhibition of RhoA geranylgeranylation/ prenylation and membrane localization—a cancer prosurvival mechanism-addresses a means to combat cardiac hypertrophy [52].

The established non-steroidal anti-inflammatory (NSAID) drug target, Cox-2, is highly relevant to my discussion of cardiac and vascular diseases and cancer overall. It is understood that Cox-2 is cardioprotective and prosurvival factor in cancer [2]. Anti-inflammatory agents such as NSAIDs logically increase cardiac risk status as these drugs target Cox-2. Mechanistically, Cox-2 is cardiocytoprotective via PKC delta [65]—a mechanism involving Cox-2/PKC delta as foretold by cancer [66]. Further, the prosurvival cascade involving EGFR, Cox-2 and MAPK acts in cancer [67] and again foretells the mechanism for prohypertrophic cardiac signaling involving Cox-2/EGFR/MAPK [68]. In the vascular system, Cox-2 is also prosurvival, thus targeting Cox-2 may alleviate pulmonary hypertension [69]. In atherogenesis, prosurvival Cox-2 is involved as a mediator. Somewhat predictably, it is involved in endothelial dysfunction/resistance to apoptosis seen in diabetic vasculature for example [70]. Along with TNFalpha
and interleukin-6, prosurvival Cox-2 forms a therapeutic target for anti-atherogenic therapies.

Further, in terms of relevance to Cox-2 mechanisms, are dietary polyunsaturated fatty acids, which may be considered broadly speaking as potential therapeutic agents in their own right. The omega-3 polyunsaturated docosahexaenoate (DHA) targets and inhibits Cox-2 along with NF-kappa B and thus reduces pro-inflammatory stimuli for atheroma development [71]. Specifically, the arachidonic lipoxygenase 15-LOX-1 metabolizes DHA, with the products of which act to downregulate Cox-2. In parallel with this observation, DHA downregulates Cox-2 and NF-kappa B in cancer [72] and the 15-LOX-1 metabolites are noted in particular in this respect [73]. Unsurprisingly, of late, DHA as an anti-growth factor is found to counter hypertension [74]. Having said this, and understanding the prosurvival mechanisms targeted by DHA from cancer, it is to be anticipated that DHA may well fail in terms of prevention of heart disease overall – a conclusion that is becoming apparent [75]– hence limiting DHA as a therapy in itself. This may be understood in light of the notion that DHA potentially targets prosurvival mechanisms in cardiomyocytes, thus countering any potential benefit to be gained from its vascular effects. This scenario underscores the importance of viewing the cardiac and vascular systems as two parts of one whole [5] when cross-comparing to cancer prosurvival mechanisms.

Other more novel therapeutics stem from considering the concept linking heart and cancer mechanistically. It is noted that increasing cellular signaling factor cAMP via phosphodiesterase III (PDEIII) targeting with cilostazol acts in concert with a DPPIV inhibitor, MK0626, in cardioprotection [76]. These effects in the diabetic disease model are associated with increase in cardiomyocyte cAMP levels and PKA activity and downstream regulation of tumour suppressor PTEN levels; downstream oncogenic prosurvival cascade activation. Amlexanox, an agent employed for decades as an immune-modulator [6], via targeting NF-kappa B noncanonical kinases TBK1 and ikkepsilon, reduces activation of the adipocyte phosphodiesterase, PDE3B. Thus Amlexanox therapy is capable in the animal model to restore PKA signaling and augment cAMP in adipocytes [77] similar to the infarct sparing cardiomyocyte mechanism in diabetes [76]. In this regard, its ability to target adipose tissue thus countering obesity and thereby have an impact on insulin-resistance lends a major future potential for this novel ‘repurposed’ agent for management of obesity/diabetes-related cardiac vascular disease.

An interesting further potential addition to the therapeutic armamentarium is the agent Allicin, (diallyl thiosulfinate), an active component in freshly crushed garlic [78]. This counteracts cardiac hypertrophic changes by decreasing levels of reactive oxygen species. Allicin significantly increased mRNA expression and protein levels of Nrf2- antioxidant signaling pathway. Notably, Allicin has been shown to act through enhancing Nrf2 levels in cancer to induce apoptosis and forms an anti-survival strategy in that context [79]. Hence cancer studies foretold Allicin’s mechanism to reduce an imbalance in pro-growth stimulus leading to cardiac hypertrophy. Table 5 outlines shared therapeutics between cancer and cardiac vascular diseases.

**Conclusion**

As was stated earlier [80], atheroma and cardiac disease such as hypertrophy and ultimate heart failure is notably in part due to a series of unbalanced growth promoting activities in the system as a whole - the ‘coronary hypothesis in hypertension’. Blood pressure lowering alone does not reverse cardiac pathology in itself and this prompts a totalistic approach – directing attention to the overall imbalance in cardiac and vascular homeostasis [5]. Disease-related imbalances and mechanisms involved in growth promotion versus inhibition in the cardiac-vascular system may be forecast from studying cancer. The aim of this article is to bring to the foreground this much overlooked strategic approach. As a reflection of this association, it has been recently stated in regards pulmonary arterial hypertension (PAH): ‘...PAH shares common aberrantly activated pathways with cancers that lead to proliferation and survival of pulmonary arterial smooth muscle cells, among others, within the artery wall and narrowing the lumen’ [81]. Therefore, cancer pro-growth factors not only align with cardio-protection but also are pro-hypertensive/atherogenic/cardiohypertrophic. In the field of cardio-oncology, it is emphasized that by targeting cancer one may also be targeting the heart vascular system [2,64]. Clinicians need to be clearly aware of this firm relation between the two since prosurvival/anti-survival mechanisms between heart/vascular system and cancer align. By taking the mechanistic ‘cue’ from cancer, one may bring forward novel therapeutics into cardiac and vascular medicine. My contention is that the highly sought after ‘holy grail’ of understanding cardioprotective mechanisms along with improved appreciation of vascular/heart disease overall may well be greatly facilitated via a detailed cross-examination of cancer itself.

**Competing interests**

The author declares that he has no competing interests.

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