Cardioprotective effect of thyroid hormone is mediated by AT2 receptor and involves nitric oxide production via Akt activation in mice

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Abstract

Studies have demonstrated that thyroid hormone (T3) can precondition the heart against ischaemic injury and improve post-ischaemic recovery. This study investigated whether the AT2 receptor (AT2R) is involved in cardioprotection and the potential molecular mechanism responsible for this effect. Hyperthyroidism was induced in male wild-type (WT) and AT2R knockout (KO) mice by administering daily intraperitoneal injections of T3 (7 μg/100 g body weight) for 14 days. The mouse hearts were harvested and perfused with a Krebs–Henseleit solution at a constant flow in a Langendorff set-up. After 30 min of stabilization, the hearts were subjected to global ischaemia for 20 min and reperfused for 45 min. Baseline cardiac function was assessed by measuring four parameters: LVDP (mmHg), heart rate (bpm), + dP/dt and − dP/dt (mmHg/s). After reperfusion, the total protein from cardiac ventricles was obtained, and the Akt signalling pathway and NO production were evaluated. Post-ischaemic functional recovery was significantly greater ($p < 0.05$) in the T3-treated WT mice compared to the control, demonstrating the cardioprotective effect of T3. This effect was abolished in T3-treated KO mice, demonstrating the physiological relevance of AT2R to the cardioprotective phenotype induced by T3. Akt activation, iNOS expression and NO production increased in cardiac tissue after T3 treatment in the WT animals, but no difference was observed after treatment in the KO mice. This study indicates that AT2R acts as a cardioprotector in the case of hyperthyroidism. Strategies targeting AT2R agonists might improve cardiac function through NO production and suggest potential therapeutic targets for heart diseases.

Keywords

Angiotensin II Cardiac hypertrophy Cardioprotection Isolated heart perfusion Thyroid hormone

Abbreviations

AMI

Acute myocardial infarction

Ang II

Angiotensin II

AT1

Angiotensin II type 1 receptor

AT2R

Angiotensin II type 2 receptor

AT2R-KO

AT2R knockout mice

C57BL/6

C57black6

+ d*P*/d*t*

First derivative of the positive ventricular pressure

– d*P*/d*t*

First derivative of the negative ventricular pressure

HR

Heart rate

I/R

Ischaemia/reperfusion

IU

International unit

KO

Knockout

KO-C

Control knockout mice

KO-T3

T3-treated knockout mice

LV

Left ventricle

LVDP

Left ventricular developed pressure

MI

Myocardial infarction

NO

Nitric oxide

RAS

Renin–angiotensin system

T3

Triiodothyronine

T4

Thyroxine

TH

Thyroid hormones

TTBS

Tween 20 tris-buffered saline

WT

Wild-type

WT-C

Wild-type control mice

WT-T3

WT T3-treated mice

WT-T3

WT T3-treated mice

Notes

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Compliance with ethical standards

Conflict of interest

The authors declare that there are no competing or financial interests associated with the manuscript.

References

1. Forini F, Kusmic C, Nicolini G, Mariani L, Zucchi R, Matteucci M, Iervasi G, Pitto L (2014) Triiodothyronine prevents cardiac ischemia/reperfusion mitochondrial impairment and cell loss by regulating miR30a/p53 axis. Endocrinology 155:4581–4590
CrossRef (https://doi.org/10.1210/en.2014-1106)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=25137026)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Triiodothyronine%20prevents%20cardiac%20ischemia%2Freperfusion%20mitochondrial%20impairment%20and%20cell%20loss%20by%20regulating%20miR30a%2Fp53%20axis&author=F.%20Forini&author=C.%20Kusmic&author=G.%20Nicolini&author=L.%20Mariani&author=R.%20Zucchi&author=M.%20Matteucci&author=G.%20Iervasi&author=L.%20Pitto&journal=Endocrinology&volume=155&pages=4581-4590&publication_year=2014)

2. Eltzschig HK, Collard CD (2004) Vascular ischaemia and reperfusion injury. Br Med Bull 70:71–86
CrossRef (https://doi.org/10.1093/bmb/ldh025)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15494470)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Vascular%20ischaemia%20and%20reperfusion%20injury&author=HK.%

20Eltzschig&author=CD.%20Collard&journal=Br%20Med%20Bull&volume=70&pages=71-86&publication_year=2004)

3. Suarez J, Wang H, Scott BT, Ling H, Makino A, Swanson E, Brown JH, Suarez JA, Feinstein S, Diaz-Juarez J, Dillmann WH (2014) In vivo selective expression of thyroid hormone receptor α1 in endothelial cells attenuates myocardial injury in experimental myocardial infarction in mice. Am J Physiol Regul Integr Comp Physiol 307:R340–R346
CrossRef (https://doi.org/10.1152/ajpregu.00449.2013)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4121632)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=24848360)
Google Scholar (http://scholar.google.com/scholar_lookup?title=In%20vivo%20selective%20expression%20of%20thyroid%20hormone%20receptor%20%CE%B11%20in%20endothelial%20cells%20attenuates%20myocardial%20injury%20in%20experimental%20myocardial%20infarction%20in%20mice&author=J.%20Suarez&author=H.%20Wang&author=BT.%20Scott&author=H.%20Ling&author=A.%20Makino&author=E.%20Swanson&author=JH.%20Brown&author=JA.%20Suarez&author=S.%20Feinstein&author=J.%20Diaz-Juarez&author=WH.%20Dillmann&journal=Am%20J%20Physiol%20Regul%20Integr%20Comp%20Physiol&volume=307&pages=R340-R346&publication_year=2014)

4. Novitzky D, Matthews N, Shawley D, Cooper DK, Zuhdi N (1991) Triiodothyronine in the recovery of stunned myocardium in dogs. Ann Thorac Surg 51:10–16
CrossRef (https://doi.org/10.1016/0003-4975(91)90438-V)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=1985544)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Triiodothyronine%20in%20the%20recovery%20of%20stunned%20myocardium%20in%20dogs&author=D.%20Novitzky&author=N.%20Matthews&author=D.%20Shawley&author=DK.%20Cooper&author=N.%20Zuhdi&journal=Ann%20Thorac%20Surg&volume=51&pages=10-16&publication_year=1991)

5. Pantos C, Mourouzis I, Saranteas T, Clavé G, Ligeret H, Noack-Fraissignes P, Renard PY, Massonneau M, Perimenis P, Spanou D, Kostopanagiotou G, Cokkinos DV (2009) Thyroid hormone improves postischaemic recovery of function while limiting apoptosis: a new therapeutic approach to support hemodynamics in the setting of ischaemia–reperfusion? Basic Res Cardiol 104:69–77
CrossRef (https://doi.org/10.1007/s00395-008-0758-4)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=19101750)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Thyroid%20hormone%20improves%20postischaemic%20recovery%20of%20function%20while%20limiting%20apoptosis%3A%20a%20new%20therapeutic%20approach%20to%20support%20hemodynamics%20in%20the%20setting%20of%20ischaemia%E2%80%93reperfusion%3F&author=C.%20Pantos&author=I.%20Mourouzis&author=T.%20Saranteas&author=G.%20Clav%C3%A9&author=H.%20Ligeret&author=P.%20Noack-Fraissignes&author=PY.%20Renard&author=M.%20Massonneau&author=P.%20Perimenis&author=D.%20Spanou&author=G.%20Kostopanagiotou&author

=DV.%20Cokkinos&journal=Basic%20Res%20Cardiol&volume=104&pages=69-77&publication_year=2009)

6. Tavares FM, da Silva IB, Gomes DA, Barreto-Chaves ML (2013) Angiotensin II type 2 receptor (AT2R) is associated with increased tolerance of the hyperthyroid heart to ischemia–reperfusion. Cardiovasc Drugs Ther 27:393–402
CrossRef (https://doi.org/10.1007/s10557-013-6473-x)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=23807455)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20II%20type%202%20receptor%20%28AT2R%29%20is%20associated%20with%20increased%20tolerance%20of%20the%20hyperthyroid%20heart%20to%20ischemia%E2%80%93reperfusion&author=FM.%20Tavares&author=IB.%20Silva&author=DA.%20Gomes&author=ML.%20Barreto-Chaves&journal=Cardiovasc%20Drugs%20Ther&volume=27&pages=393-402&publication_year=2013)

7. Pantos C, Paizis I, Mourouzis I, Moraitis P, Tzeis S, Karamanoli E, Mourouzis C, Karageorgiou H, Cokkinos DV (2005) Blockade of angiotensin II type 1 receptor diminishes cardiac hypertrophy, but does not abolish thyroxin-induced preconditioning. Horm Metab Res 37:500–504
CrossRef (https://doi.org/10.1055/s-2005-870317)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16138263)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Blockade%20of%20angiotensin%20II%20type%201%20receptor%20diminishes%20cardiac%20hypertrophy%2C%20but%20does%20not%20abolish%20thyroxin-induced%20preconditioning&author=C.%20Pantos&author=I.%20Paizis&author=I.%20Mourouzis&author=P.%20Moraitis&author=S.%20Tzeis&author=E.%20Karamanoli&author=C.%20Mourouzis&author=H.%20Karageorgiou&author=DV.%20Cokkinos&journal=Horm%20Metab%20Res&volume=37&pages=500-504&publication_year=2005)

8. Kahaly GJ, Dillmann WH (2005) Thyroid hormone action in the heart. Endocr Rev 26:704–728
CrossRef (https://doi.org/10.1210/er.2003-0033)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15632316)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Thyroid%20hormone%20action%20in%20the%20heart&author=GJ.%20Kahaly&author=WH.%20Dillmann&journal=Endocr%20Rev&volume=26&pages=704-728&publication_year=2005)

9. Klein I, Ojamaa K (2001) Thyroid hormone and the cardiovascular system. N Engl J Med 344:501–509
CrossRef (https://doi.org/10.1056/NEJM200102153440707)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11172193)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Thyroid%20hormone%20and%20the%20cardiovascular%20system&author=I.%20Klein&author=K.%20Ojamaa&journal=N%20Engl%20J%20Med&volume=344&pages=501-509&publication_year=2001)

10. Barreto-Chaves ML, Carrillo-Sepúlveda MA, Carneiro-Ramos MS, Gomes DA, Diniz GP (2010) The crosstalk between thyroid hormones and the renin–

angiotensin system. Vascul Pharmacol 52:166–170
CrossRef (https://doi.org/10.1016/j.vph.2009.10.009)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=19857605)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20crosstalk%20between%20thyroid%20hormones%20and%20the%20renin%E2%80%93angiotensin%20system&author=ML.%20Barreto-Chaves&author=MA.%20Carrillo-Sep%C3%BAlveda&author=MS.%20Carneiro-Ramos&author=DA.%20Gomes&author=GP.%20Diniz&journal=Vascul%20Pharmacol&volume=52&pages=166-170&publication_year=2010)

11. Carrillo-Sepúlveda MA, Ceravolo GS, Furstenau CR, Monteiro PS, Bruno-Fortes Z, Carvalho MH, Laurindo FR, Tostes RC, Webb RC, Barreto-Chaves ML (2013) Emerging role of angiotensin type 2 receptor (AT2R)/Akt/NO pathway in vascular smooth muscle cell in the hyperthyroidism. PLoS One 8:e61982
CrossRef (https://doi.org/10.1371/journal.pone.0061982)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3634851)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=23637941)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Emerging%20role%20of%20angiotensin%20type%202%20receptor%20%28AT2R%29%2FAkt%2FNO%20pathway%20in%20vascular%20smooth%20muscle%20cell%20in%20the%20hyperthyroidism&author=MA.%20Carrillo-Sep%C3%BAlveda&author=GS.%20Ceravolo&author=CR.%20Furstenau&author=PS.%20Monteiro&author=Z.%20Bruno-Fortes&author=MH.%20Carvalho&author=FR.%20Laurindo&author=RC.%20Tostes&author=RC.%20Webb&author=ML.%20Barreto-Chaves&journal=PLoS%20One&volume=8&pages=e61982&publication_year=2013)

12. Sumners C, de Kloet AD, Krause EG, Unger T, Steckelings UM (2015) Angiotensin type 2 receptors: blood pressure regulation and end organ damage. Curr Opin Pharmacol 21:115–121
CrossRef (https://doi.org/10.1016/j.coph.2015.01.004)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4380821)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=25677800)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20type%202%20receptors%3A%20blood%20pressure%20regulation%20and%20end%20organ%20damage&author=C.%20Sumners&author=AD.%20Kloet&author=EG.%20Krause&author=T.%20Unger&author=UM.%20Steckelings&journal=Curr%20Opin%20Pharmacol&volume=21&pages=115-121&publication_year=2015)

13. Hisatake S, Kiuchi S, Kabuki T, Oka T, Dobashi S, Ikeda T (2017) Serum angiotensin-converting enzyme 2 concentration and angiotensin-(1–7) concentration in patients with acute heart failure patients requiring emergency hospitalization. Heart Vessels 32:303–308
CrossRef (https://doi.org/10.1007/s00380-016-0877-z)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=27421979)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Serum%20angiotensin-converting%20enzyme%202%20concentration%20and%20angiotensin-

%281%E2%80%937%29%20concentration%20in%20patients%20with%20acute%20heart%20failure%20patients%20requiring%20emergency%20hospitalization&author=S.%20Hisatake&author=S.%20Kiuchi&author=T.%20Kabuki&author=T.%20Oka&author=S.%20Dobashi&author=T.%20Ikeda&journal=Heart%20Vessels&volume=32&pages=303-308&publication_year=2017)

14. Ichihara S, Senbonmatsu T, Price E Jr, Ichiki T, Gaffney FA, Inagami T (2001) Angiotensin II type 2 receptor is essential for left ventricular hypertrophy and cardiac fibrosis in chronic angiotensin II-induced hypertension. Circulation 104:346–351
CrossRef (https://doi.org/10.1161/01.CIR.104.3.346)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11457756)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20II%20type%202%20receptor%20is%20essential%20for%20left%20ventricular%20hypertrophy%20and%20cardiac%20fibrosis%20in%20chronic%20angiotensin%20II-induced%20hypertension&author=S.%20Ichihara&author=T.%20Senbonmatsu&author=E.%20Price&author=T.%20Ichiki&author=FA.%20Gaffney&author=T.%20Inagami&journal=Circulation&volume=104&pages=346-351&publication_year=2001)

15. Senbonmatsu T, Saito T, Landon EJ, Watanabe O, Price E Jr, Roberts RL, Imboden H, Fitzgerald TG, Gaffney FA, Inagami T (2003) A novel angiotensin II type 2 receptor signaling pathway: possible role in cardiac hypertrophy. EMBO J 22:6471–6482
CrossRef (https://doi.org/10.1093/emboj/cdg637)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC291832)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=14657020)
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20novel%20angiotensin%20II%20type%202%20receptor%20signaling%20pathway%3A%20possible%20role%20in%20cardiac%20hypertrophy&author=T.%20Senbonmatsu&author=T.%20Saito&author=EJ.%20Landon&author=O.%20Watanabe&author=E.%20Price&author=RL.%20Roberts&author=H.%20Imboden&author=TG.%20Fitzgerald&author=FA.%20Gaffney&author=T.%20Inagami&journal=EMBO%20J&volume=22&pages=6471-6482&publication_year=2003)

16. Porrello ER, D'Amore A, Curl CL, Allen AM, Harrap SB, Thomas WG, Delbridge LM (2009) Angiotensin II type 2 receptor antagonizes angiotensin II type 1 receptor-mediated cardiomyocyte autophagy. Hypertension 53:1032–1040
CrossRef (https://doi.org/10.1161/HYPERTENSIONAHA.108.128488)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=19433781)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20II%20type%202%20receptor%20antagonizes%20angiotensin%20II%20type%201%20receptor-mediated%20cardiomyocyte%20autophagy&author=ER.%20Porrello&author=A.%20D%E2%80%99Amore&author=CL.%20Curl&author=AM.%20Allen&author=SB.%20Harrap&author=WG.%20Thomas&author=LM.%20Delbridge&journal=Hypertension&volume=53&pages=1032-1040&publication_year=2009)

17. Chiu AT, Duncia JV, McCall DE, Wong PC, Price WA Jr, Thoolen MJ, Carini DJ, Johnson AL, Timmermans PB (1989) Nonpeptide angiotensin II receptor

antagonists. III. Structure–function studies. J Pharmacol Exp Ther 250:867–874
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=2778716)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nonpeptide%20angiotensin%20II%20receptor%20antagonists.%20III.%20Structure%E2%80%93function%20studies&author=AT.%20Chiu&author=JV.%20Duncia&author=DE.%20McCall&author=PC.%20Wong&author=WA.%20Price&author=MJ.%20Thoolen&author=DJ.%20Carini&author=AL.%20Johnson&author=PB.%20Timmermans&journal=J%20Pharmacol%20Exp%20Ther&volume=250&pages=867-874&publication_year=1989)

18. Oishi Y, Ozono R, Yano Y, Teranishi Y, Akishita M, Horiuchi M, Oshima T, Kambe M (2003) Cardioprotective role of AT2 receptor in postinfarction left ventricular remodeling. Hypertension 41:814–818
CrossRef (https://doi.org/10.1161/01.HYP.0000048340.53100.43)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12624001)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Cardioprotective%20role%20of%20AT2%20receptor%20in%20postinfarction%20left%20ventricular%20remodeling&author=Y.%20Oishi&author=R.%20Ozono&author=Y.%20Yano&author=Y.%20Teranishi&author=M.%20Akishita&author=M.%20Horiuchi&author=T.%20Oshima&author=M.%20Kambe&journal=Hypertension&volume=41&pages=814-818&publication_year=2003)

19. Adachi Y, Saito Y, Kishimoto I, Harada M, Kuwahara K, Takahashi N, Kawakami R, Nakanishi M, Nakagawa Y, Tanimoto K, Saitoh Y, Yasuno S, Usami S, Iwai M, Horiuchi M, Nakao K (2003) Angiotensin II type 2 receptor deficiency exacerbates heart failure and reduces survival after acute myocardial infarction in mice. Circulation 107:2406–2408
CrossRef (https://doi.org/10.1161/01.CIR.0000072763.98069.B4)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12732609)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20II%20type%202%20receptor%20deficiency%20exacerbates%20heart%20failure%20and%20reduces%20survival%20after%20acute%20myocardial%20infarction%20in%20mice&author=Y.%20Adachi&author=Y.%20Saito&author=I.%20Kishimoto&author=M.%20Harada&author=K.%20Kuwahara&author=N.%20Takahashi&author=R.%20Kawakami&author=M.%20Nakanishi&author=Y.%20Nakagawa&author=K.%20Tanimoto&author=Y.%20Saitoh&author=S.%20Yasuno&author=S.%20Usami&author=M.%20Iwai&author=M.%20Horiuchi&author=K.%20Nakao&journal=Circulation&volume=107&pages=2406-2408&publication_year=2003)

20. Yang Z, Bove CM, French BA, Epstein FH, Berr SS, DiMaria JM, Gibson JJ, Carey RM, Kramer CM (2002) Angiotensin II type 2 receptor overexpression preserves left ventricular function after myocardial infarction. Circulation 106:106–111
CrossRef (https://doi.org/10.1161/01.CIR.0000020014.14176.6D)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12093778)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20II%20type%202%20receptor%20overexpression%20preserves%20left%20ventricular%20function%20after%20myocardial%20infarction&author=Z.%20Yang&author=CM.%20Bove&author=BA.%20French&author

=FH.%20Epstein&author=SS.%20Berr&author=JM.%20DiMaria&author=JJ.%20Gibson&author=RM.%20Carey&author=CM.%20Kramer&journal=Circulation&volume=106&pages=106-111&publication_year=2002)

21. Bove CM, Gilson WD, Scott CD, Epstein FH, Yang Z, Dimaria JM, Berr SS, French BA, Bishop SP, Kramer CM (2005) The angiotensin II type 2 receptor and improved adjacent region function post-MI. J Cardiovasc Magn Reson 7:459–464
CrossRef (https://doi.org/10.1081/JCMR-200053461)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15881529)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20angiotensin%20II%20type%202%20receptor%20and%20improved%20adjacent%20region%20function%20post-MI&author=CM.%20Bove&author=WD.%20Gilson&author=CD.%20Scott&author=FH.%20Epstein&author=Z.%20Yang&author=JM.%20Dimaria&author=SS.%20Berr&author=BA.%20French&author=SP.%20Bishop&author=CM.%20Kramer&journal=J%20Cardiovasc%20Magn%20Reson&volume=7&pages=459-464&publication_year=2005)

22. Diniz GP, Carneiro-Ramos MS, Barreto-Chaves ML (2007) Angiotensin type 1 (AT1) and type 2 (AT2) receptors mediate the increase in TGF-beta1 in thyroid hormone-induced cardiac hypertrophy. Pflugers Arch 454:75–81
CrossRef (https://doi.org/10.1007/s00424-006-0192-0)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17206447)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20type%201%20%28AT1%29%20and%20type%202%20%28AT2%29%20receptors%20mediate%20the%20increase%20in%20TGF-beta1%20in%20thyroid%20hormone-induced%20cardiac%20hypertrophy&author=GP.%20Diniz&author=MS.%20Carneiro-Ramos&author=ML.%20Barreto-Chaves&journal=Pflugers%20Arch&volume=454&pages=75-81&publication_year=2007)

23. Carneiro-Ramos MS, Diniz GP, Nadu AP, Almeida J, Vieira RL, Santos RA, Barreto-Chaves ML (2010) Blockage of angiotensin II type 2 receptor prevents thyroxine-mediated cardiac hypertrophy by blocking Akt activation. Basic Res Cardiol 105:325–335
CrossRef (https://doi.org/10.1007/s00395-010-0089-0)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=20155476)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Blockage%20of%20angiotensin%20II%20type%202%20receptor%20prevents%20thyroxine-mediated%20cardiac%20hypertrophy%20by%20blocking%20Akt%20activation&author=MS.%20Carneiro-Ramos&author=GP.%20Diniz&author=AP.%20Nadu&author=J.%20Almeida&author=RL.%20Vieira&author=RA.%20Santos&author=ML.%20Barreto-Chaves&journal=Basic%20Res%20Cardiol&volume=105&pages=325-335&publication_year=2010)

24. Bove CM, Yang Z, Gilson WD, Epstein FH, French BA, Berr SS, Bishop SP, Matsubara H, Carey RM, Kramer CM (2004) Nitric oxide mediates benefits of angiotensin II type 2 receptor overexpression during post-infarct remodeling. Hypertension 43:680–685

CrossRef (https://doi.org/10.1161/01.HYP.0000115924.94236.91)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=14732725)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide%20mediates%20benefits%20of%C2%A0angiotensin%20II%20type%202%20receptor%C2%A0overexpression%20during%20post-infarct%20remodeling&author=CM.%20Bove&author=Z.%20Yang&author=WD.%20Gilson&author=FH.%20Epstein&author=BA.%20French&author=SS.%20Berr&author=SP.%20Bishop&author=H.%20Matsubara&author=RM.%20Carey&author=CM.%20Kramer&journal=Hypertension&volume=43&pages=680-685&publication_year=2004)

25. Kim JS, Ohshima S, Pediaditakis P, Lemasters JJ (2004) Nitric oxide: a signaling molecule against mitochondrial permeability transition- and pH-dependent cell death after reperfusion. Free Radic Biol Med 37:1943–1950
CrossRef (https://doi.org/10.1016/j.freeradbiomed.2004.09.014)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15544914)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide%3A%20a%20signaling%20molecule%20against%20mitochondrial%20permeability%20transition-%20and%20pH-dependent%20cell%20death%20after%C2%A0reperfusion&author=JS.%20Kim&author=S.%20Ohshima&author=P.%20Pediaditakis&author=JJ.%20Lemasters&journal=Free%20Radic%20Biol%20Med&volume=37&pages=1943-1950&publication_year=2004)

26. Costa AD, Garlid KD, West IC, Lincoln TM, Downey JM, Cohen MV, Critz SD (2005) Protein kinase G transmits the cardioprotective signal from cytosol to mitochondria. Circ Res 97:329–336
CrossRef (https://doi.org/10.1161/01.RES.0000178451.08719.5b)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16037573)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Protein%20kinase%20G%20transmits%20the%20cardioprotective%20signal%20from%20cytosol%20to%20mitochondria&author=AD.%20Costa&author=KD.%20Garlid&author=IC.%20West&author=TM.%20Lincoln&author=JM.%20Downey&author=MV.%20Cohen&author=SD.%20Critz&journal=Circ%20Res&volume=97&pages=329-336&publication_year=2005)

27. Cuong DV, Kim N, Youm JB, Joo H, Warda M, Lee JW, Park WS, Kim T, Kang S, Kim H, Han J (2006) Nitric oxide-cGMP-protein kinase G signaling pathway induces anoxic preconditioning through activation of ATP-sensitive K^+ channels in rat hearts. Am J Physiol Heart Circ Physiol 290:H1808–H1817
CrossRef (https://doi.org/10.1152/ajpheart.00772.2005)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16339835)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide-cGMP-protein%20kinase%20G%20signaling%20pathway%20induces%20anoxic%20preconditioning%20through%20activation%20of%20ATP-sensitive%20K%2B%20channels%20in%20rat%20hearts&author=DV.%20Cuong&author=N.%20Kim&author=JB.%20Youm&author=H.%20Joo&author=M.%20Warda&author=JW.%20Lee&author=WS.%20Park&author=T.%20Kim&author=S.%20Kang&author=H.%20Kim&author=J.%20Han&journal=Am%20J

%20Physiol%20Heart%20Circ%20Physiol&volume=290&pages=H1808-H1817&publication_year=2006)

28. Burwell LS, Brookes PS (2008) Mitochondria as a target for the cardioprotective effects of nitric oxide in ischemia–reperfusion injury. Antioxid Redox Signal 10:579–599
CrossRef (https://doi.org/10.1089/ars.2007.1845)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18052718)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Mitochondria%20as%20a%20target%20for%20the%20cardioprotective%20effects%20of%C2%A0nitric%20oxide%C2%A0in%20ischemia%E2%80%93reperfusion%20injury&author=LS.%20Burwell&author=PS.%20Brookes&journal=Antioxid%20Redox%20Signal&volume=10&pages=579-599&publication_year=2008)

29. Carrillo-Sepúlveda MA, Ceravolo GS, Fortes ZB, Carvalho MH, Tostes RC, Laurindo FR, Webb RC, Barreto-Chaves ML (2010) Thyroid hormone stimulates NO production via activation of the PI3K/Akt pathway in vascular myocytes. Cardiovasc Res 85:560–570
CrossRef (https://doi.org/10.1093/cvr/cvp304)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=19734167)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Thyroid%20hormone%20stimulates%20NO%20production%20via%20activation%20of%20the%20PI3K%2FAkt%20pathway%20in%20vascular%20myocytes&author=MA.%20Carrillo-Sep%C3%BAlveda&author=GS.%20Ceravolo&author=ZB.%20Fortes&author=MH.%20Carvalho&author=RC.%20Tostes&author=FR.%20Laurindo&author=RC.%20Webb&author=ML.%20Barreto-Chaves&journal=Cardiovasc%20Res&volume=85&pages=560-570&publication_year=2010)

30. Ichiki T, Labosky PA, Shiota C, Okuyama S, Imagawa Y, Fogo A, Niimura F, Ichikawa I, Hogan BL, Inagami T (1995) Effects on blood pressure and exploratory behaviour of mice lacking angiotensin II type-2 receptor. Nature 377(6551):748–750
CrossRef (https://doi.org/10.1038/377748a0)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=7477267)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Effects%20on%20blood%20pressure%20and%20exploratory%20behaviour%20of%20mice%20lacking%20angiotensin%20II%20type-2%20receptor&author=T.%20Ichiki&author=PA.%20Labosky&author=C.%20Shiota&author=S.%20Okuyama&author=Y.%20Imagawa&author=A.%20Fogo&author=F.%20Niimura&author=I.%20Ichikawa&author=BL.%20Hogan&author=T.%20Inagami&journal=Nature&volume=377&issue=6551&pages=748-750&publication_year=1995)

31. Reichelt ME, Willems L, Hack BA, Peart JN, Headrick JP (2009) Cardiac and coronary function in the Langendorff-perfused mouse heart model. Exp Physiol 94:54–70
CrossRef (https://doi.org/10.1113/expphysiol.2008.043554)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18723581)

Google Scholar (http://scholar.google.com/scholar_lookup?title=Cardiac%20and%20coronary%20function%20in%20the%20Langendorff-perfused%20mouse%20heart%20model&author=ME.%20Reichelt&author=L.%20Willems&author=BA.%20Hack&author=JN.%20Peart&author=JP.%20Headrick&journal=Exp%20Physiol&volume=94&pages=54-70&publication_year=2009)

32. Liao R, Podesser BK, Lim CC (2012) The continuing evolution of the Langendorff and ejecting murine heart: new advances in cardiac phenotyping. Am J Physiol Heart Circ Physiol 303:H156–H167
CrossRef (https://doi.org/10.1152/ajpheart.00333.2012)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3404701)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=22636675)
Google Scholar (http://scholar.google.com/scholar_lookup?title=The%20continuing%20evolution%20of%20the%20Langendorff%20and%20ejecting%20murine%20heart%3A%20new%20advances%20in%20cardiac%20phenotyping&author=R.%20Liao&author=BK.%20Podesser&author=CC.%20Lim&journal=Am%20J%20Physiol%20Heart%20Circ%20Physiol&volume=303&pages=H156-H167&publication_year=2012)

33. Lino CA, da Silva IB, Shibata CE, Monteiro P, Barreto-Chaves ML (2015) Maternal hyperthyroidism increases the susceptibility of rat adult offspring to cardiovascular disorders. Mol Cell Endocrinol 416:1–8
CrossRef (https://doi.org/10.1016/j.mce.2015.08.015)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=26277399)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Maternal%20hyperthyroidism%20increases%20the%20susceptibility%20of%20rat%20adult%20offspring%20to%20cardiovascular%20disorders&author=CA.%20Lino&author=IB.%20Silva&author=CE.%20Shibata&author=P.%20Monteiro&author=ML.%20Barreto-Chaves&journal=Mol%20Cell%20Endocrinol&volume=416&pages=1-8&publication_year=2015)

34. Bradford MM (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem 72:248–254
CrossRef (https://doi.org/10.1016/0003-2697(76)90527-3)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=942051)
Google Scholar (http://scholar.google.com/scholar_lookup?title=A%20rapid%20and%20sensitive%20method%20for%20the%20quantitation%20of%20microgram%20quantities%20of%20protein%20utilizing%20the%20principle%20of%20protein-dye%20binding&author=MM.%20Bradford&journal=Anal%20Biochem&volume=72&pages=248-254&publication_year=1976)

35. Hebeda CB, Teixeira SA, Tamura EK, Muscará MN, de Mello SB, Markus RP, Farsky SH (2011) Nitric oxide modulates lipopolysaccharide-induced endothelial platelet endothelial cell adhesion molecule expression via interleukin-10. Clin Exp Immunol 165:172–179
CrossRef (https://doi.org/10.1111/j.1365-2249.2011.04396.x)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3142642)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=21564091)

Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide%20modulates%20lipopolysaccharide-induced%20endothelial%20platelet%20endothelial%20cell%20adhesion%20molecule%20expression%20via%20interleukin-10&author=CB.%20Hebeda&author=SA.%20Teixeira&author=EK.%20Tamura&author=MN.%20Muscar%C3%A1&author=SB.%20Mello&author=RP.%20Markus&author=SH.%20Farsky&journal=Clin%20Exp%20Immunol&volume=165&pages=172-179&publication_year=2011)

36. Singh KD, Karnik SS (2016) Angiotensin receptors: structure, function, signaling and clinical applications. J Cell Signal 1:111–118
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4976824)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=27512731)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20receptors%3A%20structure%2C%20function%2C%20signaling%20and%20clinical%20applications&author=KD.%20Singh&author=SS.%20Karnik&journal=J%20Cell%20Signal&volume=1&pages=111-118&publication_year=2016)

37. Hein L, Barsh GS, Pratt RE, Dzau VJ, Kobilka BK (1995) Behavioural and cardiovascular effects of disrupting the angiotensin II type-2 receptor in mice. Nature 377:744–747
CrossRef (https://doi.org/10.1038/377744a0)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=7477266)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Behavioural%20and%20cardiovascular%20effects%20of%20disrupting%20the%C2%A0angiotensin%20II%20type-2%20receptor%20in%20mice&author=L.%20Hein&author=GS.%20Barsh&author=RE.%20Pratt&author=VJ.%20Dzau&author=BK.%20Kobilka&journal=Nature&volume=377&pages=744-747&publication_year=1995)

38. Kobori H, Ichihara A, Miyashita Y, Hayashi M, Saruta T (1999) Local renin–angiotensin system contributes to hyperthyroidism-induced cardiac hypertrophy. J Endocrinol 160:43–47
CrossRef (https://doi.org/10.1677/joe.0.1600043)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2573048)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9854175)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Local%20renin%E2%80%93angiotensin%20system%20contributes%20to%20hyperthyroidism-induced%20cardiac%20hypertrophy&author=H.%20Kobori&author=A.%20Ichihara&author=Y.%20Miyashita&author=M.%20Hayashi&author=T.%20Saruta&journal=J%20Endocrinol&volume=160&pages=43-47&publication_year=1999)

39. Shimoura H, Tanaka H, Matsumoto K, Mochizuki Y, Hatani Y, Hatazawa K, Matsuzoe H, Ooka J, Sano H, Sawa T, Motoji Y, Ryo-Koriyama K, Hirata KI (2017) Effects of a changeover from other angiotensin II receptor blockers to olmesartan on left ventricular hypertrophy in heart failure patients. Heart Vessels 32:584–590
CrossRef (https://doi.org/10.1007/s00380-016-0904-0)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=27722772)

Google Scholar (http://scholar.google.com/scholar_lookup?title=Effects%20of%20a%20changeover%20from%20other%20angiotensin%20II%20receptor%20blockers%20to%20olmesartan%20on%20left%20ventricular%20hypertrophy%20in%20heart%20failure%20patients&author=H.%20Shimoura&author=H.%20Tanaka&author=K.%20Matsumoto&author=Y.%20Mochizuki&author=Y.%20Hatani&author=K.%20Hatazawa&author=H.%20Matsuzoe&author=J.%20Ooka&author=H.%20Sano&author=T.%20Sawa&author=Y.%20Motoji&author=K.%20Ryo-Koriyama&author=KI.%20Hirata&journal=Heart%20Vessels&volume=32&pages=584-590&publication_year=2017)

40. Senbonmatsu T, Ichihara S, Price E Jr, Gaffney FA, Inagami T (2000) Evidence for angiotensin II type 2 receptor-mediated cardiac myocyte enlargement during in vivo pressure overload. J Clin Investig 106:R25–R29
CrossRef (https://doi.org/10.1172/JCI10037)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC314331)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10930448)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Evidence%20for%20angiotensin%20II%20type%202%20receptor-mediated%20cardiac%20myocyte%20enlargement%20during%20in%20vivo%20pressure%20overload&author=T.%20Senbonmatsu&author=S.%20Ichihara&author=E.%20Price&author=FA.%20Gaffney&author=T.%20Inagami&journal=J%20Clin%20Investig&volume=106&pages=R25-R29&publication_year=2000)

41. Akishita M, Iwai M, Wu L, Zhang L, Ouchi Y, Dzau VJ, Horiuchi M (2000) Inhibitory effect of angiotensin II type 2 receptor on coronary arterial remodeling after aortic banding in mice. Circulation 102:1684–1689
CrossRef (https://doi.org/10.1161/01.CIR.102.14.1684)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11015348)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Inhibitory%20effect%20of%20angiotensin%20II%20type%202%20receptor%20on%20coronary%20arterial%20remodeling%20after%20aortic%20banding%20in%20mice&author=M.%20Akishita&author=M.%20Iwai&author=L.%20Wu&author=L.%20Zhang&author=Y.%20Ouchi&author=VJ.%20Dzau&author=M.%20Horiuchi&journal=Circulation&volume=102&pages=1684-1689&publication_year=2000)

42. Bliksøen M, Rutkovskiy A, Vaage J, Stensløkken KO (2017) Mode of perfusion influences infarct size, coronary flow and stress kinases in the isolated mouse heart. Acta Physiol (Oxf) 220:36–46
CrossRef (https://doi.org/10.1111/apha.12773)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Mode%20of%20perfusion%20influences%20infarct%20size%2C%20coronary%20flow%20and%20stress%20kinases%20in%20the%20isolated%20mouse%20heart&author=M.%20Bliks%C3%B8en&author=A.%20Rutkovskiy&author=J.%20Vaage&author=KO.%20Stensl%C3%B8kken&journal=Acta%20Physiol%20%28Oxf%29&volume=220&pages=36-46&publication_year=2017)

43. Pantos C, Mourouzis I, Saranteas T, Brozou V, Galanopoulos G, Kostopanagiotou G, Cokkinos DV (2011) Acute T3 treatment protects the heart against ischemia-reperfusion injury via TRα1 receptor. Mol Cell Biochem 353:235–241
CrossRef (https://doi.org/10.1007/s11010-011-0791-8)

PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=21442236)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Acute%20T3%20treatment%20protects%20the%20heart%20against%20ischemia-reperfusion%20injury%20via%20TR%CE%B11%20receptor&author=C.%20Pantos&author=I.%20Mourouzis&author=T.%20Saranteas&author=V.%20Brozou&author=G.%20Galanopoulos&author=G.%20Kostopanagiotou&author=DV.%20Cokkinos&journal=Mol%20Cell%20Biochem&volume=353&pages=235-241&publication_year=2011)

44. Pantos CI, Malliopoulou VA, Mourouzis IS, Karamanoli EP, Paizis IA, Steimberg N, Varonos DD, Cokkinos DV (2002) Long-term thyroxine administration protects the heart in a pattern similar to ischemic preconditioning. Thyroid 12:325–329
CrossRef (https://doi.org/10.1089/10507250252949469)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12034058)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Long-term%20thyroxine%20administration%20protects%20the%20heart%20in%20a%20pattern%20similar%20to%20ischemic%C2%A0preconditioning&author=CI.%20Pantos&author=VA.%20Malliopoulou&author=IS.%20Mourouzis&author=EP.%20Karamanoli&author=IA.%20Paizis&author=N.%20Steimberg&author=DD.%20Varonos&author=DV.%20Cokkinos&journal=Thyroid&volume=12&pages=325-329&publication_year=2002)

45. Jeddi S, Zaman J, Ghasemi A (2015) Effects of ischemic postconditioning on the hemodynamic parameters and heart nitric oxide levels of hypothyroid rats. Arq Bras Cardiol 104:136–143
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4375657)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=25424164)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Effects%20of%20ischemic%20postconditioning%20on%20the%20hemodynamic%20parameters%20and%20heart%20nitric%20oxide%20levels%20of%20hypothyroid%20rats&author=S.%20Jeddi&author=J.%20Zaman&author=A.%20Ghasemi&journal=Arq%20Bras%20Cardiol&volume=104&pages=136-143&publication_year=2015)

46. Gerdes AM, Ojamaa K (2016) Thyroid hormone and cardioprotection. Compr Physiol 6:1199–1219
CrossRef (https://doi.org/10.1002/cphy.c150012)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=27347890)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Thyroid%20hormone%20and%20cardioprotection&author=AM.%20Gerdes&author=K.%20Ojamaa&journal=Compr%20Physiol&volume=6&pages=1199-1219&publication_year=2016)

47. Sabatino L, Kusmic C, Nicolini G, Amato R, Casini G, Iervasi G, Balzan S (2016) T3 enhances Ang2 in rat aorta in myocardial I/R: comparison with left ventricle. J Mol Endocrinol 57:139–149
CrossRef (https://doi.org/10.1530/JME-16-0118)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=27444191)

Google Scholar (http://scholar.google.com/scholar_lookup?title=T3%20enhances%20Ang2%20in%20rat%20aorta%20in%20myocardial%20I%2FR%3A%20comparison%20with%20left%20ventricle&author=L.%20Sabatino&author=C.%20Kusmic&author=G.%20Nicolini&author=R.%20Amato&author=G.%20Casini&author=G.%20Iervasi&author=S.%20Balzan&journal=J%20Mol%20Endocrinol&volume=57&pages=139-149&publication_year=2016)

48. Jeddi S, Zaman J, Zadeh-Vakili A, Zarkesh M, Ghasemi A (2016) Involvement of inducible nitric oxide synthase in the loss of cardioprotection by ischemic postconditioning in hypothyroid rats. Gene 580:169–176
CrossRef (https://doi.org/10.1016/j.gene.2016.01.014)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=26774797)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Involvement%20of%20inducible%20nitric%20oxide%20synthase%20in%20the%20loss%20of%20cardioprotection%20by%20ischemic%20postconditioning%20in%20hypothyroid%20rats&author=S.%20Jeddi&author=J.%20Zaman&author=A.%20Zadeh-Vakili&author=M.%20Zarkesh&author=A.%20Ghasemi&journal=Gene&volume=580&pages=169-176&publication_year=2016)

49. Yuan X, Niu HT, Wang PL, Lu J, Zhao H, Liu SH, Zheng QS, Li CG (2015) Cardioprotective effect of licochalcone D against myocardial ischemia/reperfusion injury in Langendorff-perfused rat hearts. PLoS One 10:e0128375
CrossRef (https://doi.org/10.1371/journal.pone.0128375)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4461317)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=26058040)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Cardioprotective%20effect%20of%20licochalcone%20D%20against%20myocardial%20ischemia%2Freperfusion%20injury%20in%20Langendorff-perfused%20rat%20hearts&author=X.%20Yuan&author=HT.%20Niu&author=PL.%20Wang&author=J.%20Lu&author=H.%20Zhao&author=SH.%20Liu&author=QS.%20Zheng&author=CG.%20Li&journal=PLoS%20One&volume=10&pages=e0128375&publication_year=2015)

50. Rajagopalan V, Zhang Y, Pol C, Costello C, Seitter S, Lehto A, Savinova OV, Chen YF, Gerdes AM (2017) Modified low-dose triiodo-l-thyronine therapy safely improves function following myocardial ischemia–reperfusion injury. Front Physiol 8:225
CrossRef (https://doi.org/10.3389/fphys.2017.00225)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC5388763)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=28446882)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Modified%20low-dose%20triiodo-l-thyronine%20therapy%20safely%20improves%20function%20following%20myocardial%C2%A0ischemia%E2%80%93reperfusion%C2%A0injury&author=V.%20Rajagopalan&author=Y.%20Zhang&author=C.%20Pol&author=C.%20Costello&author=S.%20Seitter&author=A.%20Lehto&author=OV.%20Savinova&author=YF.%20Chen&author=AM.%20Gerdes&journal=Front%20Physiol&volume=8&pages=225&publication_year=2017)

51. Diniz GP, Carneiro-Ramos MS, Barreto-Chaves ML (2009) Angiotensin type 1 receptor mediates thyroid hormone-induced cardiomyocyte hypertrophy

through the Akt/GSK-3beta/mTOR signaling pathway. Basic Res Cardiol 104:653–667
CrossRef (https://doi.org/10.1007/s00395-009-0043-1)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=19588183)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Angiotensin%20type%201%20receptor%20mediates%20thyroid%20hormone-induced%20cardiomyocyte%20hypertrophy%20through%20the%20Akt%2FGSK-3beta%2FmTOR%20signaling%20pathway&author=GP.%20Diniz&author=MS.%20Carneiro-Ramos&author=ML.%20Barreto-Chaves&journal=Basic%20Res%20Cardiol&volume=104&pages=653-667&publication_year=2009)

52. Caruso-Neves C, Kwon SH, Guggino WB (2005) Albumin endocytosis in proximal tubule cells is modulated by angiotensin II through an AT2 receptor-mediated protein kinase B activation. Proc Natl Acad Sci USA 102:17513–17518
CrossRef (https://doi.org/10.1073/pnas.0507255102)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1297674)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16293694)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Albumin%20endocytosis%20in%20proximal%20tubule%20cells%20is%20modulated%20by%20angiotensin%20II%20through%20an%20AT2%20receptor-mediated%20protein%20kinase%20B%20activation&author=C.%20Caruso-Neves&author=SH.%20Kwon&author=WB.%20Guggino&journal=Proc%20Natl%20Acad%20Sci%20USA&volume=102&pages=17513-17518&publication_year=2005)

53. O'Donnell VB, Chumley PH, Hogg N, Bloodsworth A, Darley-Usmar VM, Freeman BA (1997) Nitric oxide inhibition of lipid peroxidation: kinetics of reaction with lipid peroxylradicals and comparison with alpha-tocopherol. Biochemistry 36:15216–15223
CrossRef (https://doi.org/10.1021/bi971891z)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9398249)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide%20inhibition%20of%20lipid%20peroxidation%3A%20kinetics%20of%20reaction%20with%20lipid%20peroxylradicals%20and%20comparison%20with%20alpha-tocopherol&author=VB.%20O%E2%80%99Donnell&author=PH.%20Chumley&author=N.%20Hogg&author=A.%20Bloodsworth&author=VM.%20Darley-Usmar&author=BA.%20Freeman&journal=Biochemistry&volume=36&pages=15216-15223&publication_year=1997)

54. Moncada S, Erusalimsky JD (2002) Does nitric oxide modulate mitochondrial energy generation and apoptosis? Nat Rev Mol Cell Biol 3:214–220
CrossRef (https://doi.org/10.1038/nrm762)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11994742)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Does%20nitric%20oxide%20modulate%20mitochondrial%20energy%20generation%20and%20apoptosis%3F&author=S.%20Moncada&author=JD.%20

Erusalimsky&journal=Nat%20Rev%20Mol%20Cell%20Biol&volume=3&pages=214-220&publication_year=2002)

55. Rössig L, Fichtlscherer B, Breitschopf K, Haendeler J, Zeiher AM, Mülsch A, Dimmeler S (1999) Nitric oxide inhibits caspase-3 by S-nitrosation in vivo. J Biol Chem 274:6823–6826
CrossRef (https://doi.org/10.1074/jbc.274.11.6823)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10066732)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Nitric%20oxide%20inhibits%20caspase-3%20by%20S-nitrosation%20in%20vivo&author=L.%20R%C3%B6ssig&author=B.%20Fichtlscherer&author=K.%20Breitschopf&author=J.%20Haendeler&author=AM.%20Zeiher&author=A.%20M%C3%BClsch&author=S.%20Dimmeler&journal=J%20Biol%20Chem&volume=274&pages=6823-6826&publication_year=1999)

56. Trochu JN, Bouhour JB, Kaley G, Hintze TH (2000) Role of endothelium-derived nitric oxide in the regulation of cardiac oxygen metabolism: implications in health and disease. Circ Res 87:1108–1117
CrossRef (https://doi.org/10.1161/01.RES.87.12.1108)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11110767)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Role%20of%20endothelium-derived%20nitric%20oxide%20in%20the%20regulation%20of%20cardiac%20oxygen%20metabolism%3A%20implications%20in%20health%20and%20disease&author=JN.%20Trochu&author=JB.%20Bouhour&author=G.%20Kaley&author=TH.%20Hintze&journal=Circ%20Res&volume=87&pages=1108-1117&publication_year=2000)

57. West MB, Rokosh G, Obal D, Velayutham M, Xuan YT, Hill BG, Keith RJ, Schrader J, Guo Y, Conklin DJ, Prabhu SD, Zweier JL, Bolli R, Bhatnagar A (2008) Cardiac myocyte-specific expression of inducible nitric oxide synthase protects against ischemia/reperfusion injury by preventing mitochondrial permeability transition. Circulation 118:1970–1978
CrossRef (https://doi.org/10.1161/CIRCULATIONAHA.108.791533)
PubMedCentral (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763350)
PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18936326)
Google Scholar (http://scholar.google.com/scholar_lookup?title=Cardiac%20myocyte-specific%20expression%20of%20inducible%20nitric%20oxide%20synthase%20protects%20against%20ischemia%2Freperfusion%20injury%20by%20preventing%20mitochondrial%20permeability%20transition&author=MB.%20West&author=G.%20Rokosh&author=D.%20Obal&author=M.%20Velayutham&author=YT.%20Xuan&author=BG.%20Hill&author=RJ.%20Keith&author=J.%20Schrader&author=Y.%20Guo&author=DJ.%20Conklin&author=SD.%20Prabhu&author=JL.%20Zweier&author=R.%20Bolli&author=A.%20Bhatnagar&journal=Circulation&volume=118&pages=1970-1978&publication_year=2008)

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