

Peptidyl-prolyl cis/trans isomerases in GtoPdb v.2023.1

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Abstract

Peptidyl-prolyl cis/trans isomerases (PPIases) are an enzyme family which catalyse the cis/trans isomerisation of proline peptide bonds to promote the folding and re-folding of peptides and proteins. Three subfamilies have been identified: cyclophilins, FK506-binding proteins and parvulins. Individual PPIases are overexpressed in a number of cancers [62], and family members have been targeted for immunosuppressant effects.

Contents

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Database links

Peptidyl-prolyl cis/trans isomerases

<https://www.guidetopharmacology.org/GRAC/FamilyDisplayForward?familyId=845>

Introduction to Peptidyl-prolyl cis/trans isomerases

<https://www.guidetopharmacology.org/GRAC/FamilyIntroductionForward?familyId=845>

Enzymes

FKBP12(FKBP prolyl isomerase 1A)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=2609>

FKBP38(FKBP prolyl isomerase 8)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3177>

FKBP51(FKBP prolyl isomerase 5)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3175>

FKBP52(FKBP prolyl isomerase 4)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3176>

FKBP prolyl isomerase like

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3178>

peptidylprolyl cis/trans isomerase, NIMA-interacting 1

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3171>

Cyclophilin A(peptidylprolyl isomerase A)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=2751>

Cyclophilin D(peptidylprolyl isomerase D)

<https://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=3179>

References

1. Annett S, Moore G and Robson T. (2020) FK506 binding proteins and inflammation related signalling pathways; basic biology, current status and future prospects for pharmacological intervention. *Pharmacol Ther* **215**: 107623 [PMID:32622856]
2. Annett S, Moore G, Short A, Marshall A, McCrudden C, Yakkundi A, Das S, McCluggage WG, Nelson L and Harley I et al.. (2020) FKBPL-based peptide, ALM201, targets angiogenesis and cancer stem cells in ovarian cancer. *Br J Cancer* **122**: 361-371 [PMID:31772325]
3. Azzolin L, Antolini N, Calderan A, Ruzza P, Sciacovelli M, Marin O, Mammi S, Bernardi P and Rasola A. (2011) Antamanide, a derivative of Amanita phalloides, is a novel inhibitor of the mitochondrial permeability transition pore. *PLoS One* **6**: e16280 [PMID:21297983]
4. Barik S. (2018) Dual-Family Peptidylprolyl Isomerases (Immunophilins) of Select Monocellular Organisms. *Biomolecules* **8** [PMID:30445770]
5. Biasutto L, Azzolini M, Szabò I and Zoratti M. (2016) The mitochondrial permeability transition pore in AD 2016: An update. *Biochim Biophys Acta* **1863**: 2515-30 [PMID:26902508]
6. Blair LJ, Baker JD, Sabbagh JJ and Dickey CA. (2015) The emerging role of peptidyl-prolyl isomerase chaperones in tau oligomerization, amyloid processing, and Alzheimer's disease. *J Neurochem* **133**: 1-13 [PMID:25628064]
7. Bracher A, Kozany C, Hähle A, Wild P, Zacharias M and Hausch F. (2013) Crystal structures of the free and ligand-bound FK1-FK2 domain segment of FKBP52 reveal a flexible inter-domain hinge. *J Mol Biol* **425**: 4134-44 [PMID:23933011]
8. Briston T, Lewis S, Koglin M, Mistry K, Shen Y, Hartopp N, Katsumata R, Fukumoto H, Duchen MR and Szabadkai G et al.. (2016) Identification of ER-000444793, a Cyclophilin D-independent inhibitor of mitochondrial permeability transition, using a high-throughput screen in cryopreserved mitochondria. *Sci Rep* **6**: 37798 [PMID:27886240]
9. Buneman P, Christie G, Davies JA, Dimitrellou R, Harding SD, Pawson AJ, Sharman JL and Wu Y. (2020) Why data citation isn't working, and what to do about it *Database* **2020** [PMID:32367113]
10. Butterfield DA, Abdul HM, Opie W, Newman SF, Joshi G, Ansari MA and Sultana R. (2006) Pin1 in Alzheimer's disease. *J Neurochem* **98**: 1697-706 [PMID:16945100]
11. Christner C, Wyrwa R, Marsch S, Küllertz G, Thiericke R, Grabley S, Schumann D and Fischer G. (1999) Synthesis and cytotoxic evaluation of cycloheximide derivatives as potential inhibitors of FKBP12 with neuroregenerative properties. *J Med Chem* **42**: 3615-22 [PMID:10479292]
12. Clarke SJ, McStay GP and Halestrap AP. (2002) Sanglifehrin A acts as a potent inhibitor of the mitochondrial permeability transition and reperfusion injury of the heart by binding to cyclophilin-D at a different site from cyclosporin A. *J Biol Chem* **277**: 34793-9 [PMID:12095984]
13. Donley C, McClelland K, McKeen HD, Nelson L, Yakkundi A, Jithesh PV, Burrows J, McClements L, Valentine A and Prise KM et al.. (2014) Identification of RBCK1 as a novel regulator of FKBPL: implications for tumor growth and response to tamoxifen. *Oncogene* **33**: 3441-50 [PMID:23912458]
14. Dube H, Selwood D, Malouitre S, Capano M, Simone MI and Crompton M. (2012) A mitochondrial-targeted cyclosporin A with high binding affinity for cyclophilin D yields improved cytoprotection of cardiomyocytes. *Biochem J* **441**: 901-7 [PMID:22035570]
15. Dubiella C, Pinch BJ, Koikawa K, Zaidman D, Poon E, Manz TD, Nabat B, He S, Resnick E and Rogel A et al.. (2021) Sulfopin is a covalent inhibitor of Pin1 that blocks Myc-driven tumors in vivo. *Nat Chem Biol* [PMID:33972797]
16. Dunyak BM and Gestwicki JE. (2016) Peptidyl-Proline Isomerasers (PPIases): Targets for Natural Products and Natural Product-Inspired Compounds. *J Med Chem* **59**: 9622-9644 [PMID:27409354]

17. Edlich F, Erdmann F, Jarczowski F, Moutty MC, Weiwad M and Fischer G. (2007) The Bcl-2 regulator FKBP38-calmodulin-Ca²⁺ is inhibited by Hsp90. *J Biol Chem* **282**: 15341-8 [[PMID:17379601](#)]
18. Edlich F and Lücke C. (2011) From cell death to viral replication: the diverse functions of the membrane-associated FKBP38. *Curr Opin Pharmacol* **11**: 348-53 [[PMID:21514222](#)]
19. Edlich F, Weiwad M, Wildemann D, Jarczowski F, Kilka S, Moutty MC, Jahreis G, Lücke C, Schmidt W and Striggow F *et al.* (2006) The specific FKBP38 inhibitor N-(N',N'-dimethylcarboxamidomethyl)cycloheximide has potent neuroprotective and neurotrophic properties in brain ischemia. *J Biol Chem* **281**: 14961-70 [[PMID:16547004](#)]
20. Elkamhawy A, Park JE, Hassan AHE, Pae AN, Lee J, Park BG and Roh EJ. (2018) Synthesis and evaluation of 2-(3-arylureido)pyridines and 2-(3-arylureido)pyrazines as potential modulators of A^β-induced mitochondrial dysfunction in Alzheimer's disease. *Eur J Med Chem* **144**: 529-543 [[PMID:29288949](#)]
21. Erlejman AG, De Leo SA, Mazaira GI, Molinari AM, Camisay MF, Fontana V, Cox MB, Piwien-Pilipuk G and Galigniana MD. (2014) NF-κB transcriptional activity is modulated by FK506-binding proteins FKBP51 and FKBP52: a role for peptidyl-prolyl isomerase activity. *J Biol Chem* **289**: 26263-26276 [[PMID:25104352](#)]
22. Esnault S, Shen ZJ and Malter JS. (2008) Pinning down signaling in the immune system: the role of the peptidyl-prolyl isomerase Pin1 in immune cell function. *Crit Rev Immunol* **28**: 45-60 [[PMID:18298383](#)]
23. Frausto SD, Lee E and Tang H. (2013) Cyclophilins as modulators of viral replication. *Viruses* **5**: 1684-701 [[PMID:23852270](#)]
24. Fruman DA, Klee CB, Bierer BE and Burakoff SJ. (1992) Calcineurin phosphatase activity in T lymphocytes is inhibited by FK 506 and cyclosporin A. *Proc Natl Acad Sci USA* **89**: 3686-90 [[PMID:1373887](#)]
25. Gaali S, Kirschner A, Cuboni S, Hartmann J, Kozany C, Balsevich G, Namendorf C, Fernandez-Vizarra P, Sippel C and Zannas AS *et al.* (2015) Selective inhibitors of the FK506-binding protein 51 by induced fit. *Nat Chem Biol* **11**: 33-7 [[PMID:25436518](#)]
26. Garcia-Touchard A, Burke SE, Toner JL, Cromack K and Schwartz RS. (2006) Zotarolimus-eluting stents reduce experimental coronary artery neointimal hyperplasia after 4 weeks. *Eur Heart J* **27**: 988-93 [[PMID:16449248](#)]
27. Ghartey-Kwansah G, Li Z, Feng R, Wang L, Zhou X, Chen FZ, Xu MM, Jones O, Mu Y and Chen S *et al.* (2018) Comparative analysis of FKBP family protein: evaluation, structure, and function in mammals and *Drosophila melanogaster*. *BMC Dev Biol* **18**: 7 [[PMID:29587629](#)]
28. Girardini JE, Napoli M, Piazza S, Rustighi A, Marotta C, Radaelli E, Capaci V, Jordan L, Quinlan P and Thompson A *et al.* (2011) A Pin1/mutant p53 axis promotes aggressiveness in breast cancer. *Cancer Cell* **20**: 79-91 [[PMID:21741598](#)]
29. Gopalakrishnan R, Kozany C, Wang Y, Schneider S, Hoogeland B, Bracher A and Hausch F. (2012) Exploration of pipecolate sulfonamides as binders of the FK506-binding proteins 51 and 52. *J Med Chem* **55**: 4123-31 [[PMID:22455398](#)]
30. Guo C, Hou X, Dong L, Marakovits J, Greasley S, Dagostino E, Ferre R, Johnson MC, Humphries PS and Li H *et al.* (2014) Structure-based design of novel human Pin1 inhibitors (III): optimizing affinity beyond the phosphate recognition pocket. *Bioorg Med Chem Lett* **24**: 4187-91 [[PMID:25091930](#)]
31. Göthel SF and Marahiel MA. (1999) Peptidyl-prolyl cis-trans isomerases, a superfamily of ubiquitous folding catalysts. *Cell Mol Life Sci* **55**: 423-36 [[PMID:10228556](#)]
32. Hamilton GS and Steiner JP. (1998) Immunophilins: beyond immunosuppression. *J Med Chem* **41**: 5119-43 [[PMID:9857082](#)]
33. Handschumacher RE, Harding MW, Rice J, Drugge RJ and Speicher DW. (1984) Cyclophilin: a specific cytosolic binding protein for cyclosporin A. *Science* **226**: 544-7 [[PMID:6238408](#)]
34. Hansson MJ, Mattiasson G, Månsson R, Karlsson J, Keep MF, Waldmeier P, Ruegg UT, Dumont JM, Bessegħir K and Elmér E. (2004) The nonimmunosuppressive cyclosporin analogs NIM811 and UNIL025 display nanomolar potencies on permeability transition in brain-derived mitochondria. *J Bioenerg Biomembr* **36**: 407-13 [[PMID:15377880](#)]
35. Hultsch T, Müller KD, Meingassner JG, Grassberger M, Schopf RE and Knop J. (1998) Ascomycin macrolactam derivative SDZ ASM 981 inhibits the release of granule-associated mediators and of newly synthesized cytokines in RBL 2H3 mast cells in an immunophilin-dependent manner. *Arch Dermatol Res* **290**: 501-7 [[PMID:9808344](#)]
36. Ji KY, Kim SM, Yee SM, Kim MJ, Ban YJ, Kim EM, Lee EH, Choi HR, Yun H and Lee CW *et al.* (2021)

- Cyclophilin A is an endogenous ligand for the triggering receptor expressed on myeloid cells-2 (TREM2). *FASEB J* **35**: e21479 [PMID:33710680]
- 37. Khaspekov L, Friberg H, Halestrap A, Viktorov I and Wieloch T. (1999) Cyclosporin A and its nonimmunosuppressive analogue N-Me-Val-4-cyclosporin A mitigate glucose/oxygen deprivation-induced damage to rat cultured hippocampal neurons. *Eur J Neurosci* **11**: 3194-8 [PMID:10510183]
 - 38. Knaup FH, Meyners C, Sugiarto WO, Wedel S, Springer M, Walz C, Geiger TM, Schmidt M, Sisignano M and Hausch F. (2023) Structure-Based Discovery of a New Selectivity-Enabling Motif for the FK506-Binding Protein 51. *J Med Chem* [PMID:37058391]
 - 39. Kolos JM, Voll AM, Bauder M and Hausch F. (2018) FKBP Ligands-Where We Are and Where to Go? *Front Pharmacol* **9**: 1425 [PMID:30568592]
 - 40. Koren 3rd J, Jinwal UK, Davey Z, Kiray J, Arulselvam K and Dickey CA. (2011) Bending tau into shape: the emerging role of peptidyl-prolyl isomerases in tauopathies. *Mol Neurobiol* **44**: 65-70 [PMID:21523562]
 - 41. Kuglstatter A, Mueller F, Kusznir E, Gsell B, Stihle M, Thoma R, Benz J, Aspeslet L, Freitag D and Hennig M. (2011) Structural basis for the cyclophilin A binding affinity and immunosuppressive potency of E-ISA247 (voclosporin). *Acta Crystallogr D Biol Crystallogr* **67**: 119-23 [PMID:21245533]
 - 42. Kuo J, Bobardt M, Chatterji U, Mayo PR, Trepanier DJ, Foster RT, Gallay P and Ure DR. (2019) A Pan-Cyclophilin Inhibitor, CRV431, Decreases Fibrosis and Tumor Development in Chronic Liver Disease Models. *J Pharmacol Exp Ther* **371**: 231-241 [PMID:31406003]
 - 43. Lammers M, Neumann H, Chin JW and James LC. (2010) Acetylation regulates cyclophilin A catalysis, immunosuppression and HIV isomerization. *Nat Chem Biol* **6**: 331-7 [PMID:20364129]
 - 44. Liou YC, Sun A, Ryo A, Zhou XZ, Yu ZX, Huang HK, Uchida T, Bronson R, Bing G and Li X et al.. (2003) Role of the prolyl isomerase Pin1 in protecting against age-dependent neurodegeneration. *Nature* **424**: 556-61 [PMID:12891359]
 - 45. Liu J, Farmer Jr JD, Lane WS, Friedman J, Weissman I and Schreiber SL. (1991) Calcineurin is a common target of cyclophilin-cyclosporin A and FKBP-FK506 complexes. *Cell* **66**: 807-15 [PMID:1715244]
 - 46. Lu KP and Zhou XZ. (2007) The prolyl isomerase PIN1: a pivotal new twist in phosphorylation signalling and disease. *Nat Rev Mol Cell Biol* **8**: 904-16 [PMID:17878917]
 - 47. Lu PJ, Wulf G, Zhou XZ, Davies P and Lu KP. (1999) The prolyl isomerase Pin1 restores the function of Alzheimer-associated phosphorylated tau protein. *Nature* **399**: 784-8 [PMID:10391244]
 - 48. Luger T, Van Leent EJ, Graeber M, Hedgecock S, Thurston M, Kandra A, Berth-Jones J, Bjerke J, Christophers E and Knop J et al.. (2001) SDZ ASM 981: an emerging safe and effective treatment for atopic dermatitis. *Br J Dermatol* **144**: 788-94 [PMID:11298538]
 - 49. Maestre-Martínez M, Haupt K, Edlich F, Jahreis G, Jarczowski F, Erdmann F, Fischer G and Lücke C. (2010) New structural aspects of FKBP38 activation. *Biol Chem* **391**: 1157-67 [PMID:20707607]
 - 50. Malouitre S, Dube H, Selwood D and Crompton M. (2009) Mitochondrial targeting of cyclosporin A enables selective inhibition of cyclophilin-D and enhanced cytoprotection after glucose and oxygen deprivation. *Biochem J* **425**: 137-48 [PMID:19832699]
 - 51. McClements L, Annett S, Yakkundi A, O'Rourke M, Valentine A, Moustafa N, Alqudah A, Simões BM, Furlong F and Short A et al.. (2019) FKBPL and its peptide derivatives inhibit endocrine therapy resistant cancer stem cells and breast cancer metastasis by downregulating DLL4 and Notch4. *BMC Cancer* **19**: 351 [PMID:30975104]
 - 52. McClements L, Annett S, Yakkundi A and Robson T. (2015) The Role of Peptidyl Prolyl Isomerases in Aging and Vascular Diseases. *Curr Mol Pharmacol* **9**: 165-79 [PMID:25986561]
 - 53. McClements L, Yakkundi A, Papaspyropoulos A, Harrison H, Ablett MP, Jithesh PV, McKeen HD, Bennett R, Donley C and Kissenspennig A et al.. (2013) Targeting treatment-resistant breast cancer stem cells with FKBPL and its peptide derivative, AD-01, via the CD44 pathway. *Clin Cancer Res* **19**: 3881-93 [PMID:23741069]
 - 54. McKeen HD, McAlpine K, Valentine A, Quinn DJ, McClelland K, Byrne C, O'Rourke M, Young S, Scott CJ and McCarthy HO et al.. (2008) A novel FK506-like binding protein interacts with the glucocorticoid receptor and regulates steroid receptor signaling. *Endocrinology* **149**: 5724-34 [PMID:18669603]
 - 55. Nath R. (2017) Peptidyl-prolyl isomerase (PPIase): an emerging area in tumor biology *Cancer Res Front* **3**: 126-143
 - 56. Nechama M, Kwon J, Wei S, Kyi AT, Welner RS, Ben-Dov IZ, Arredouani MS, Asara JM, Chen CH and Tsai CY et al.. (2018) The IL-33-PIN1-IRAK-M axis is critical for type 2 immunity in IL-33-induced allergic

- airway inflammation. *Nat Commun* **9**: 1603 [PMID:29686383]
57. Oh J and Malter JS. (2013) Pin1-FADD interactions regulate Fas-mediated apoptosis in activated eosinophils. *J Immunol* **190**: 4937-45 [PMID:23606538]
58. Pastorino L, Sun A, Lu PJ, Zhou XZ, Balastik M, Finn G, Wulf G, Lim J, Li SH and Li X *et al.*. (2006) The prolyl isomerase Pin1 regulates amyloid precursor protein processing and amyloid-beta production. *Nature* **440**: 528-34 [PMID:16554819]
59. Pinch BJ, Doctor ZM, Nabet B, Browne CM, Seo HS, Mohardt ML, Kozono S, Lian X, Manz TD and Chun Y *et al.*. (2020) Identification of a potent and selective covalent Pin1 inhibitor. *Nat Chem Biol* **16**: 979-987 [PMID:32483379]
60. Porter Jr GA and Beutner G. (2018) Cyclophilin D, Somehow a Master Regulator of Mitochondrial Function. *Biomolecules* **8** [PMID:30558250]
61. Qiu C, Albayram O, Kondo A, Wang B, Kim N, Arai K, Tsai CY, Bassal MA, Herbert MK and Washida K *et al.*. (2021) Cis P-tau underlies vascular contribution to cognitive impairment and dementia and can be effectively targeted by immunotherapy in mice *Sci Transl Med* [PMID:34078745]
62. Rippmann JF, Hobbie S, Daiber C, Guilliard B, Bauer M, Birk J, Nar H, Garin-Chesa P, Rettig WJ and Schnapp A. (2000) Phosphorylation-dependent proline isomerization catalyzed by Pin1 is essential for tumor cell survival and entry into mitosis. *Cell Growth Differ* **11**: 409-16 [PMID:10939594]
63. Robson T and James IF. (2012) The therapeutic and diagnostic potential of FKBP; a novel anticancer protein. *Drug Discov Today* **17**: 544-8 [PMID:22265918]
64. Saibil H. (2013) Chaperone machines for protein folding, unfolding and disaggregation. *Nat Rev Mol Cell Biol* **14**: 630-42 [PMID:24026055]
65. Shirane M and Nakayama KI. (2003) Inherent calcineurin inhibitor FKBP38 targets Bcl-2 to mitochondria and inhibits apoptosis. *Nat Cell Biol* **5**: 28-37 [PMID:12510191]
66. Shore ER, Awais M, Kershaw NM, Gibson RR, Pandalaneni S, Latawiec D, Wen L, Javed MA, Criddle DN and Berry N *et al.*. (2016) Small Molecule Inhibitors of Cyclophilin D To Protect Mitochondrial Function as a Potential Treatment for Acute Pancreatitis. *J Med Chem* **59**: 2596-611 [PMID:26950392]
67. Stifani S. (2018) The Multiple Roles of Peptidyl Prolyl Isomerases in Brain Cancer. *Biomolecules* **8**: 112 [PMID:30314361]
68. Storer CL, Dickey CA, Galigniana MD, Rein T and Cox MB. (2011) FKBP51 and FKBP52 in signaling and disease. *Trends Endocrinol Metab* **22**: 481-90 [PMID:21889356]
69. Sunnotel O, Hiripi L, Lagan K, McDaid JR, De León JM, Miyagawa Y, Crowe H, Kaluskar S, Ward M and Scullion C *et al.*. (2010) Alterations in the steroid hormone receptor co-chaperone FKBP are associated with male infertility: a case-control study. *Reprod Biol Endocrinol* **8**: 22 [PMID:20210997]
70. Theuerkorn M, Fischer G and Schiene-Fischer C. (2011) Prolyl cis/trans isomerase signalling pathways in cancer. *Curr Opin Pharmacol* **11**: 281-7 [PMID:21497135]
71. Valentine A, O'Rourke M, Yakkundi A, Worthington J, Hookham M, Bicknell R, McCarthy HO, McClelland K, McCallum L and Dyer H *et al.*. (2011) FKBP and peptide derivatives: novel biological agents that inhibit angiogenesis by a CD44-dependent mechanism. *Clin Cancer Res* **17**: 1044-56 [PMID:21364036]
72. Waldmeier PC, Feldtrauer JJ, Qian T and Lemasters JJ. (2002) Inhibition of the mitochondrial permeability transition by the nonimmunosuppressive cyclosporin derivative NIM811. *Mol Pharmacol* **62**: 22-9 [PMID:12065751]
73. Warne J, Pryce G, Hill JM, Shi X, Lennerås F, Puentes F, Kip M, Hilditch L, Walker P and Simone MI *et al.*. (2016) Selective Inhibition of the Mitochondrial Permeability Transition Pore Protects against Neurodegeneration in Experimental Multiple Sclerosis. *J Biol Chem* **291**: 4356-73 [PMID:26679998]
74. Wei S, Yoshida N, Finn G, Kozono S, Nechama M, Kyttaris VC, Zhen Zhou X, Tsokos GC and Ping Lu K. (2016) Pin1-Targeted Therapy for Systemic Lupus Erythematosus. *Arthritis Rheumatol* **68**: 2503-13 [PMID:27159270]
75. Yakkundi A, McCallum L, O'Kane A, Dyer H, Worthington J, McKeen HD, McClements L, Elliott C, McCarthy HO and Hirst DG *et al.*. (2013) The anti-migratory effects of FKBP and its peptide derivative, AD-01: regulation of CD44 and the cytoskeletal pathway. *PLoS One* **8**: e55075 [PMID:23457460]
76. Yurchenko V, Constant S, Eisenmesser E and Bukrinsky M. (2010) Cyclophilin-CD147 interactions: a new target for anti-inflammatory therapeutics. *Clin Exp Immunol* **160**: 305-17 [PMID:20345978]
77. Zheng H, You H, Zhou XZ, Murray SA, Uchida T, Wulf G, Gu L, Tang X, Lu KP and Xiao ZX. (2002) The prolyl isomerase Pin1 is a regulator of p53 in genotoxic response. *Nature* **419**: 849-53 [PMID:12397361]

78. Zuberbier T, Chong SU, Grunow K, Guhl S, Welker P, Grassberger M and Henz BM. (2001) The ascomycin macrolactam pimecrolimus (Elidel, SDZ ASM 981) is a potent inhibitor of mediator release from human dermal mast cells and peripheral blood basophils. *J Allergy Clin Immunol* **108**: 275-80 [[PMID:11496246](#)]
79. Šileikytė J and Forte M. (2016) Shutting down the pore: The search for small molecule inhibitors of the mitochondrial permeability transition. *Biochim Biophys Acta* **1857**: 1197-1202 [[PMID:26924772](#)]