多糖调控T/B淋巴细胞免疫应答机制的研究进展

易 阳[1,2] 曹 银[3] 张名位[1]*

([1]广东省农业科学院农业生物技术研究所, 广州 510610; [2]华中农业大学食品科技学院, 武汉 430070;
[3]湖北大学知行学院, 武汉 430011)

摘要 淋巴细胞是机体适应性免疫系统的重要组成, 多糖对其刺激作用在生物医药领域受到广泛的关注。目前, 大部分的相关研究仅限于多糖对淋巴细胞增殖及细胞因子或抗体表达水平的调控, 系统的分子机制解析少见报道。综合多糖对淋巴细胞的免疫调节作用发现: 活性多糖可同时刺激T/B细胞、也可选择性刺激T细胞或选择性刺激B细胞; 多糖刺激T细胞免疫应答的信号通道主要为TCR/CD3→PTK→PI3-K→PKC/PLCγ→Ca^{2+}→calcineurin→NFAT和TCR/CD3→PTK→MAPKs→AP-1; 而刺激B细胞的信号通道主要包括TLR2/4→TRAF6→IKKc→NF-κB、TLR2/4→PTK→MAPKs→AP-1和IgM/CD79→PTK→MAPKs→AP-1。同时, 归纳多糖刺激淋巴细胞活性的构效关系, 旨在为相关领域的研究提供参考。

关键词 多糖; T淋巴细胞; B淋巴细胞; 免疫; 信号通路

1 引言

多糖是一种广谱的生物应答调节剂, 具有免疫调节、抗肿瘤、抗衰老、抗炎症及抗病毒等多种功能活性[1]。作为天然的大分子活性物质, 多糖在调节机体免疫功能的同时不会产生显著的毒副作用[2-3], 是临床上理想的免疫佐剂, 如香菇多糖、云芝糖肽、裂殖菌多糖等[1]。T/B淋巴细胞分别调节机体的细胞/体液免疫应答, 是适应性免疫系统的主要效应细胞。多糖能调节T/B细胞周期, 刺激其分裂增殖, 并促进相关细胞因子和抗体的分泌[4-10], 但其作用机制鲜见系统的研究报道。本文综述了多糖对T/B淋巴细胞的免疫调节作用及相关分子机制, 以期系统地把握多糖刺激淋巴细胞免疫应答的信号转导途径。

2 多糖对淋巴细胞的免疫调节作用

2.1 同时刺激T/B细胞

对于多糖同时刺激T/B细胞增殖的结论一般是建立在混合的脾细胞体系中, 且分别以ConA和LPS诱导的增殖来评价T和B细胞活性[10-11]。从灵芝中分离到的富含半乳糖的胞外多糖GLP-2[12]和乌头多糖FPS-1[11]都能在体外分别促进ConA和LPS诱导的小鼠淋巴细胞增殖, 同时还能通过腹腔注射在体内增强T、B细胞活性。此外, 重蜜环菌多糖[13]、猪苓多糖[14]和细辛多糖[15]也表现出类似的活性。Leung等[16]发现, 芦荟多糖在体外能分别刺激T、B细胞增殖, 但相同剂量下B细胞的刺激指数约为T细胞刺激指数的5倍。在体外的脾细胞体系或宿主内环境中, 多糖可能并不同时直接作用于T、B细胞刺激免疫应答。

2.2 选择性刺激T细胞

枸杞多糖LBP、LBPF4和LBPF5均能选择性地促进小鼠T细胞增殖, 虽未能如ConA显著增加脾淋巴细胞S和G_2/M期的细胞比例, 但却显著降低了细胞凋亡和sub-G_1期的细胞数量[6]。此外, 泥鳅粘液多糖[10]、冬虫夏草多糖[7]、柔枝槐多糖[9]、采绒革盖菌多糖[17]、香菇多糖[5,18-19]和裂殖菌多糖[18]都能选择性刺激T细胞, 主要表现为: 体内或体外刺激T细胞增殖; 对B细胞活性及其抗体分泌无影响或作用甚微; 能促进T细胞IL-2、IL-4、IL-6、IL-8和IFN-γ的表达。

2.3 选择性刺激B细胞

Han等研究发现, 刺五加多糖[8,20]和当归多糖[21]均能直接刺激B细胞的增殖、分化及抗体生成, 但对T细胞的增殖及IL-2、IL-4、IL-6和IFN-γ的表达无影响。通过腹腔注射桔梗多糖PG, 绵羊红细胞免疫小鼠的B细胞增殖和多克隆IgM抗体表达显著增强,

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*通讯作者。Tel: 020-38469791, E-mail: mwzhh@vip.tom.com

而Th1细胞IL-2表达和Th2细胞IL-4表达不受影响[22]。此外, B细胞选择性刺激多糖还包括富含阿拉伯聚糖的樱桃多糖[23]、斑鸠菊阿拉伯半乳聚糖[24]和采绒革盖菌蛋白多糖[25]。柴胡果胶多糖bupleuran 2IIc能延长B细胞周期中S和G_2/M的过渡期, 并诱导B细胞中成视网膜母细胞瘤Rb蛋白(参与细胞周期调控并涉及细胞周期中G_0/G_1到S期过渡的限制点调节的抑癌蛋白)的磷酸化[4]。

2.4 其他作用

肺炎杆菌多糖K1CPS能激活多种细胞毒素效应细胞, 在体内外增强杀伤细胞(lymphokine-activated killer cells, LAKC)的抗肿瘤活性, 抑制WEHI-164肿瘤细胞的生长并显著降低肿瘤小鼠的肉瘤质量, 其作用可能涉及CD3+LAKC亚型的增加[26]。当H_2O_2浓度达200 μmol/L时能导致小鼠脾淋巴细胞的凋亡, 而50~400 μg/mL的蕨麻多糖能剂量依赖性显著降低H_2O_2诱导的细胞内氧化损伤, 减少细胞的凋亡数量[27]。裂蹄木层孔菌多糖能增强淋巴NK细胞的杀伤功能[28]。此外, Zhang等[29]发现, 枸杞多糖能促进BALB/C小鼠脾细胞增殖, 但对纯化的T或B淋巴细胞无刺激作用, 进一步研究证实B细胞增殖与巨噬细胞的激活密切相关。因此, 多糖刺激脾细胞增殖并不能说明其靶细胞为淋巴细胞。

3 多糖对T/B淋巴细胞免疫调节的作用机制

多糖通过复杂的信号转导途径刺激淋巴细胞免疫应答, 其信号通路的研究存在一定的经验性和复制性。目前, 推导多糖刺激淋巴细胞免疫信号通路的方法主要有两种。其一, 通过已知受体的抗体或已知激酶的抑制剂来阻断细胞信号转导, 从而推测该受体或激酶是否参与多糖的免疫调控过程。这种方法适用性强, 在表1所列多糖的相关研究中都有

表1 多糖对T/B淋巴细胞的免疫调节作用

Table 1 Effects of polysaccharides on T/B lymphocytes

来源 Source	结构特征 Structural feature	剂量(μg/mL) Dose(μg/mL)	蛋白 Protein	内毒素 Endotoxin	细胞 Cell	作用 Effects on cells	介导受体/通路 Receptor/pathway
Acanthopanax koreanum[20]	870 kDa	1~30	—	—	B, not T	↑ Proliferation, IgM	TLR2, TLR4, CD19, CD79b, not CD38
Acanthopanax senticosus[8]		3~100	—	×	B, not T	↑ Proliferation, IgM	TLR2/4
Astragalus membranaceus[2]	Rha, Xyl, Glc, Gal, Man, Fru	50~500	×	×	B, not T	↑ Proliferation	mIg, TLR4-independent
Bupleurum falcatum[4,45-46]	rhamnogalacturonan core	100	—	—	B	↑ Ca^{2+}, cyclin(D2, A and B1), IL-6	PTK→PI3-K→PLCγ →PKC/calcineurin, PTK →MEK→ERK, IgM
Cordyceps sinensis[7]	82 kDa Glc, Man, Gal	6.25~100	—	×	T	↑ Proliferation, IL-2, IL-4, IL-8	ERK
Ganoderma lucidum[31,48-50]	585kDa L-Fuc, D-Xyl D-Man, D-Gal, D-GlcNAc, D-Glc	5~500	<6.5%	×	B, not T	↑ Proliferation, IgM, IL-1β, IL-6, IL-12, IFN-γ, TNF-α, GM-CSF, G-CSF, M-CSF, CD71, CD25	TLR2/4→p38MAPK →Blimp-1, TLR2/4→ MAPKs/IKKc→Ig
Lycium barbarum[6]	150~290 kDa	1~300	1.2% ~23.5%	—	T, not B	↑ Proliferation, IL-2, IFN-γ	CD25→NFAT, AP-1
Misgurnus anguillicaudatus[10]	130 kDa D-Gal, L-Fuc, D-Man	1~100	—	—	T, not B	↑ Proliferation, IL-2, IL-4, IL-6, IFN-γ	
Phellinus linteus[28,47]	15 kDa Man, Glc, Gal	10~500	—	×	B, not T	↑ Proliferation, CD80 and CD86	PTK, PKC
Platycodon grandiflorum[22]	Inulin-type polyfructose	1~100	—	×	B, not T	↑ Proliferation, IgM	CD19, CD79b
Sophora subprosrate[9]	22.4 kDa α-(1→4)-D-Glc	50~400	—	×	T	↑ NO, IL-2	PKC, Ca^{2+}

×: 未检出或可忽略; —: 未检测; ↑: 促进或增加。

×: not detected or negligible; —: not tested; ↑: increased.

应用; 其二, 通过比较多糖对特定受体突变型及其野生型的刺激作用来判断该受体是否转导信号。C3H/HeJ小鼠是TLR4受体的突变株, 其*Tlr4*基因在编码区发生点突变, 712位点的脯氨酸被组氨酸取代[30]。它和野生型C3H/HeN小鼠是研究黄芪多糖[2]、刺五加多糖[8,20]和灵芝多糖[31]作用受体的关键。但这种方法受特定基因突变模型的限制, 仅适用于TLR4介导的B细胞信号通路研究。

3.1 T细胞免疫刺激信号转导

T细胞受体(T-cell receptor, TCR)对抗原的亲和力相对较弱, 一般与CD3形成复合体, 然后识别结合主要组织相容性复合体(MHC I/II)分子形成TCR共受体(TCR co-receptor), 并介导T细胞的激活。多糖对T细胞的刺激作用可能主要涉及胞质内蛋白激酶的磷酸化和脱磷酸作用, 而且很大程度上依赖于Src族激酶的酪氨酸磷酸化转导胞内信号[32]。冬虫夏草多糖能刺激T淋巴细胞增殖和相关细胞因子的分泌, 且能短时间内诱导细胞外信号调节激酶(ERK1/2)的磷酸化, 而其活性在加入ERK抑制剂后丧失, 说明多糖对T淋巴细胞的激活涉及MAPK通路[7]。枸杞多糖LBPs能促进T细胞跨膜蛋白CD25的表达, 激活NFAT(nuclear factor of activated T cells)和AP-1转录因子, 并诱导*IL-2*和*IFN-γ*基因的转录和蛋白质合成[6]。但LBPs对核因子NF-κB无影响, 可能因为NF-κB的激活主要由巨噬细胞分泌的TNF-α和IL-1β的协同刺激[6]。此外, NFAT活性受神经钙蛋白调控[33], LBPs的作用可能还与细胞Ca^{2+}流通有关联。经柔枝槐多糖SSP1刺激的T淋巴细胞膜上蛋白激酶C(PKC)活性和胞质中游离Ca^{2+}浓度都有增加。进一步研究发现钙离子阻滞剂硝苯地平(Nifedipine)能抑制SSP1对T细胞的刺激作用, 且SSP1刺激过程产生PKC的易位[9]。细胞内Ca^{2+}浓度的微量增加能导致PKC活化, 而PKC活性的抑制也在一定程度上降低Ca^{2+}的胞内流, 受PTK激发的PKC由细胞质向细胞膜迁移是Ca^{2+}流通的关键[34-35]。综上, 活性多糖刺激T细胞免疫应答的信号通道主要归纳为两条(图1), 包括TCR/CD3→PTK→PI3-K→ PKC/PLCγ→Ca^{2+}→calcineurin→NFAT 和 TCR/CD3→PTK→MAPKs→AP-1, 可能不涉及NF-κB信号通路。

3.2 B细胞免疫刺激信号转导

B细胞受体(B-cell receptor, BCR)是一种位于B细胞膜表面的跨膜受体蛋白, 由IgM和CD79组成[36]。BCR介导的信号调节还涉及一些共受体, 如B细胞

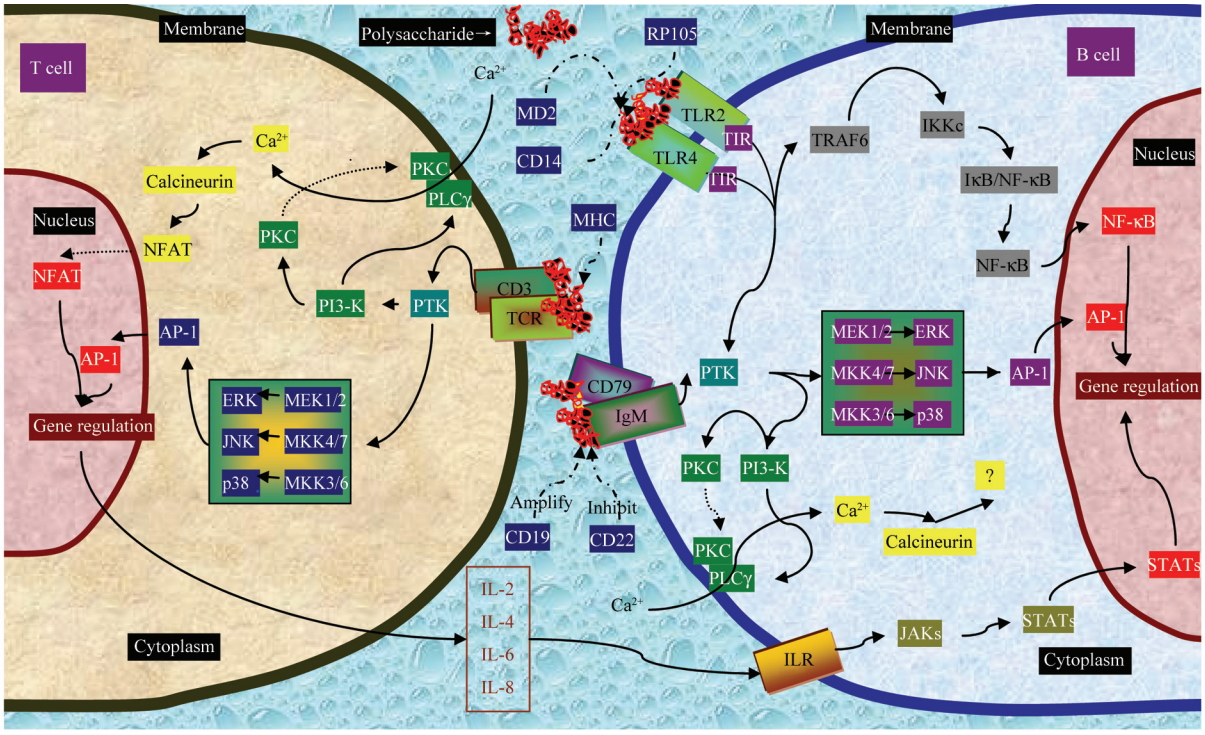

图1　多糖刺激T/B细胞免疫应答的信号通路

Fig.1　The signaling pathways of T/B lymphocyte stimulated by polysaccharides

特异性糖蛋白CD19和CD38[36-38]。CD19和CD79b抗体均能抑制桔梗多糖诱导的B细胞增殖, 说明CD19和CD79b都参与了多糖的刺激过程[22]。CD19与膜免疫球蛋白(mIg)结合能协同放大mIg介导的MAPKs(ERK2、JNK和p38)激活, 降低抗原刺激阈值2个数量级, 而CD22的作用相反[39]。CD22与mIg或mIg-CD19复合体结合能抑制MAPKs的激活, 消除CD22影响后, MAPKs的活化得到增强。CD19和CD22对mIg介导的MAPKs激活的相反作用主要源于不同的抗原受体亲和力[39]。此外, CD19还涉及CD38介导的未成熟B细胞的信号级联反应, 通过lyn和PI3-K活化刺激细胞生长, 但CD38并不影响桔梗多糖的刺激信号[22,40]。

膜荚黄芪多糖ASP能刺激C3H/HeJ小鼠B淋巴细胞增殖, 而对BALB/c小鼠B细胞增殖的促进作用被mIg抗体明显抑制[2], 说明ASP主要通过mIg介导B细胞活性, 并不依赖TLR4。然而, TLR4与ASP[8]和灵芝多糖[31]选择性增强B细胞活性有着密切的联系。多糖ASP对C3H/HeJ小鼠B细胞的刺激作用要显著弱于C3H/HeN小鼠, 且ASP对B细胞的刺激作用在分别加入TLR4和TLR2抗体后减弱。ASP通过TLR2/4介导的途径诱导MAPKs(ERK1/2、p38和JNK)和转录因子NF-κB激活[8]。尽管ASP刺激的信号通路与LPS相似, 但LPS的特异性抑制剂多粘霉素B(PMB)并未减弱ASP的活性。相比C3H/HeN小鼠, LPS对C3H/HeJ小鼠B细胞的作用减弱了90%, 而ASP的作用只减弱了49%~66%[8]。TLR2也参与LPS刺激的B细胞免疫应答[41-42], 在*TLR4*基因缺乏的B细胞中, TLR2可能与其他TLRs形成二聚体或低聚物, 转导ASP刺激信号。TLR2/4抗体可能通过空间位阻等机制干扰TLRs二聚体或低聚物的形成, 从而阻断LPS和ASP的刺激信号[8]。Shao等[31]研究发现, 灵芝多糖能选择性刺激BALB/c小鼠脾B细胞增殖, 而对C3H/HeJ小鼠B细胞无影响。此外, TLR4抗体能显著抑制灵芝多糖的活性, 且TLR4抗体和mIg抗体的协同作用几乎能完全阻断多糖的刺激信号, APS和灵芝多糖能直接经mIg和TLR4介导B细胞激活, 而这两种多糖之间存在竞争机制。值得注意的是, 胎牛血清中含有一种相对分子质量为31 kDa的蛋白(不能与ASP结合), 能特异性结合灵芝多糖, 增强其刺激作用[31], 可能类似CD14、RP105和MD2等衔接蛋白促进多糖和TLR4的结合[43-44]。相似的研究也证实刺五加多糖通过TLR2、TLR4、CD19和CD79b发挥其B细胞刺激活性[20]。

柴胡果胶多糖bupleuran 2IIc/PG-1通过B细胞中多种蛋白酪氨酸残基的磷酸化促进细胞周期蛋白D2(Cyclin D2)的表达。PTK、Src家族酪氨酸激酶(PP2)、PI3-K、PLCγ、PKC、神经钙蛋白和受体操纵钙通道的抑制剂都能显著降低bupleuran 2IIc/PG-1诱导的Cyclin D2的表达。此外, Cyclin D2的表达在MEK1和MEK1/2抑制剂的作用下略有下降, 但不受p38 MAPK抑制剂影响[45]。IgM抗体能在几分钟内刺激ERK的磷酸化, 而bupleuran 2IIc/PG-1的相同作用发生在120分钟后, 多糖对B细胞的作用可能不受BCR的介导。Cyclin D2的诱导表达可能是bupleuran 2IIc/PG-1的直接刺激作用, 因为相关激酶活化和钙离子调节反应在多糖刺激的几分钟内就发生了[45]。IL-6参与IgM的表达, 当B细胞体系中加入IL-6抗体后, 多糖bupleuran 2IIc刺激的IgM生成降低[46]。类似的, 裂蹄木层孔菌多糖PL也能经PTK和PKC途径促进小鼠B细胞的增殖和共刺激分子CD80和CD86的表达, 并引发细胞中Ca^{2+}内流和反应氧中介物(reactive oxygen intermediates, ROI)的生成[47]。

综上, 活性多糖刺激B细胞免疫应答的信号转导途径主要归纳为三条(图1), 包括TLR2/4→TRAF6→IKKc→NF-κB、TLR2/4→PTK→MAPKs→AP-1和IgM/CD79→PTK→MAPKs→AP-1。而多糖也能经IgM/CD79刺激神经钙蛋白的活化, 但其下游信号转导未知, 可能通过影响胞内激酶调节免疫应答。

3.3 受刺激的T/B细胞间的相互作用

灵芝多糖能刺激小鼠脾细胞中IL-1、IL-6、IL-12、IFN-γ、TNF-α、GM-CSF、G-CSF和M-CSF的分泌, Chen等[48]认为多糖前期的免疫调节作用可能通过Th1细胞的免疫应答产物引发, 与多糖增加化学疗法期间或之后CD4和T细胞数量的结果吻合。但更多的报道证实, 灵芝多糖属于B细胞选择性刺激多糖, 能诱导小鼠脾淋巴细胞增殖和向IgM分泌型浆细胞的分化, 增加B细胞表面CD71+/CD25+和Ig的表达[31,49-50]。小鼠经腹腔注射裂蹄木层孔菌多糖PL后, T淋巴细胞增殖能力及细胞毒性得到增强[28]。作为B细胞的多克隆激活剂, PL还能上调T细胞依赖性和非T细胞依赖性初级抗体应答反应, 且比担子菌多糖表现出更广泛的免疫刺激和抗肿瘤活性[28]。然而, Kim等[47]之后的研究证实PL在体外主要刺激CD19+

细胞增殖, 而对CD3+细胞无影响, 说明PL的靶细胞为B细胞, 而非T细胞。Wang等[51]研究发现TLR2和TLR4抗体阻断剂均能抑制海胆黄多糖SEP诱导的免疫抑制小鼠脾细胞增殖及其IL-2分泌, 其通路可能涉及PI3-K/PKB。同时, 又发现SEP可能通过PI3-K/Erk途径激活NFAT启动子, 进一步调控肿瘤小鼠脾细胞IL-2和TNF-α的表达[52]。可见, 灵芝多糖、裂蹄木层孔菌多糖和胆黄多糖在刺激B细胞免疫应答的同时, 间接增强了T细胞活性。而T细胞的激活可能再次影响B细胞活性, 如T细胞分泌的IL-2、IL-4、IL-6和IL-8能通过ILR(interleukin receptor)介导的途径激活B细胞中STATs, 促进相关基因转录, 且IL-6可能通过该途径上调B细胞IgM的表达。

4　多糖调节T/B细胞活性的构效关系

相对分子质量大于100 kDa主要由半乳糖、阿拉伯糖、鼠李糖和甘露糖组成的多糖或蛋白多糖一般具有较高的生物活性[53-54]。聂凌鸿(博士论文《淮山活性多糖的分离纯化、结构与生物活性的研究》华南理工大学, 2004)认为, 相对分子质量大小是多糖具备生物活性的必要条件, 相对分子质量在100~200 kDa之间的多糖活性最强, 而相对分子质量低于10 kDa的通常不具有活性。由表1可见, 半乳糖和甘露糖似乎是活性多糖(15~870 kDa)刺激T/B细胞免疫应答的关键单糖组成。芦荟多糖对小鼠淋巴细胞的免疫调节作用也与其甘露糖含量和相对分子质量呈正相关性[16]。多糖通过结合细胞膜上受体介导其免疫调节活性, 相对分子质量大小可能并不是影响其活性的关键。同种多糖的高分子组分表现出相对高的免疫活性, 其本质可能在于高相对分子质量多糖含有更多重复的受体配位点, 能够与T/B细胞膜上的多糖受体交联结合, 刺激细胞免疫应答。同时, 大分子的多糖可能更易与其他刺激因子结合, 强化刺激信号。

麻黄多糖级分ESP-B1在250 μg/mL的剂量下能促进ConA诱导的小鼠脾淋巴细胞增殖, 而级分ESP-B2-4却表现出抑制作用, 其中, 以含有大量半乳糖醛酸的ESP-B4的抑制作用最强。然而, ESP-B4的抑制作用在经部分酸水解后消失, 说明多糖链的分支与其淋巴细胞刺激作用密切相关[55]。酯化度高的枣多糖级分表现出最强的小鼠脾淋巴细胞增殖促进作用[56]。蛋白含量相对高的枸杞多糖LBP、LBPF4和LBPF5具有刺激T细胞的活性, 而蛋白含量相对少的LBPF1、LBPF2和LBPF3却未表现出刺激作用。LBP、LBPF4和LBPF5经蛋白酶酶解后, 对脾淋巴细胞增殖的刺激作用显著降低, 可见结合蛋白对T细胞的刺激有重要作用[6]。同样, 刺五加多糖能选择性刺激B细胞, 且经蛋白酶K消化结合蛋白后对脾淋巴细胞增殖的促进作用并未减弱[20]。多糖的结合蛋白可能主要影响T细胞。柴胡多糖(1→3)-β-D-半乳糖主链上含末端葡萄糖酸(GlcA)或4-O-Me-GlcA的(1→6)半乳糖支链是促进B细胞有丝分裂[57]以及刺激IL-2[46]和Cyclin(D2、A和B1)表达[4,45]的重要活性结构。

5　小结

活性多糖对T/B细胞的免疫调节作用有着本质的差别, 与涉及的信号通路有密切关联。图1中多糖刺激T/B细胞的某些信号转导环节相似, 主要表现为两点。其一, 由胞内激酶活化引发Ca^{2+}内流, 并诱导神经钙蛋白活化; 其二, 胞内激酶活化激活MAPKs, 并增强AP-1结合蛋白能力以调节基因表达。但总体而言, 与B细胞相比, T细胞有着更丰富的刺激信号转导途径, 主要表现在以下几个方面: (1)B细胞膜上多糖配位受体有BCR和TLR2/4, 而T细胞只有TCR; (2)有多种胞外辅助因子能强化多糖对B细胞刺激信号; (3)多糖能通过TLR2/4激活B细胞内核转录因子NF-κB, 但可能不影响T细胞中的NF-κB; (4)B细胞的TLR2/4和BCR同时介导MAPKs的激活并促进AP-1调节的基因表达, 而T细胞中MAPKs的激活可能只由TCR介导。细胞内信号转导途径错综复杂, 多糖涉及的多条通路中各环节之间可能存在的交互作用不易判断。此外, 就多糖本身而言, 其结构复杂、解析难度大, 对多糖分子中结合受体的活性位点的阐释将为活性多糖的研究开辟新的途径。

活性多糖能通过调控T/B细胞免疫应答, 增强机体的免疫功能, 对改善由癌症和老龄化引起的机体免疫力低下有着广阔的应用前景[1,58-59]。这类活性多糖广泛存在于中药材中, 如灵芝、枸杞和人参等。此外, 人们膳食中的香菇、银耳和龙眼[60]等也含有丰富的免疫活性多糖。对多糖刺激T/B细胞免疫信号通路的研究, 其价值在于能从分子水平解释其作用机制, 明确其功能活性, 为保健产品的研发和饮食的调整提供参考, 以此改善身体状况, 预防疾病。

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Immunomodulatory Activities and Mechanisms of Polysaccharides on T/B Lymphocytes

Yi Yang[1,2], Cao Yin[3], Zhang Mingwei[1]*

([1]*Bio-technological Research Institute, Guangdong Academy of Agricultural Sciences, Guangzhou 510610, China*; [2]*College of Food Science and Technology, Huazhong Agricultural University, Wuhan 430070, China*; [3]*Zhixing College, Hubei University, Wuhan 430011, China*)

Abstract Many studies have shown their interests on the immunomodulation of natural polysaccharides. The activation of lymphocyte by polysaccharides has been widely evaluated as the enhancement of adaptive immune system. However, most of the studies just focus on the proliferation and cytokine/antibody secretion of lymphocyte without conclusive action mechanism. In the present papers, recent researches involved in the immunomodulatory polysaccharide of T/B lymphocytes were reviewed. It was concluded that polysaccharides could stimulate the activation of T/B cells simultaneously and selectively upregulate the function of T cell or B cell, the signaling pathway of T cell stimulated by polysaccharide were TCR/CD3→PTK→PI3-K→PKC/PLCγ→Ca^{2+}→calcineurin →NFAT and TCR/CD3→PTK→MAPKs→AP-1, and that of B cell were TLR2/4→TRAF6→IKKc→NF-κB, TLR2/4→PTK→MAPKs→AP-1 and IgM/CD79→PTK→MAPKs→AP-1. Meanwhile, structure-function relationship of polysaccharide on lymphocyte was summarized.

Key words polysaccharide; T lymphocyte; B lymphocyte; immune; signaling pathway

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*Corresponding author. Tel: 86-20-38469791, E-mail: mwzhh@vip.tom.com