Naturceuticals: A New Hope for Treatment of Diabetic Complications

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Submission: September 12, 2017; Published: September 22, 2017

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Introduction

Diabetes mellitus is a collection of metabolic disorders characterized by high serum glucose level in the body that is due to low insulin secretion or due to cellular unresponsiveness toward produced insulin. This high level of glucose produces the conventional symptoms of polyphagia, polydipsia and polyuria [1]. Uncontrolled diabetes can cause diverse complications, diabetic ketoacidosis and non ketotic hyperosmolar coma fall under acute complications [2] while chronic complications comprise multiple tissue damage that results in stroke, cardiovascular disease, foot ulcers, renal failure and eye damage [3]. The general features of hyperglycemia-induced tissue damage are shown schematically. The DCCT (Diabetes Control and Complications Trial) and the UKPDS (U.K. Prospective Diabetes Study) established that hyperglycemia (far left of the figure) causes the clinically manifest diabetic tissue damage (far right). It is affected by genetic determinants of individual susceptibility (top box) and by independent accelerating factors such as hypertension (bottom box); the (inner boxes) is the mechanisms that mediate the tissue-damaging effects of hyperglycemia [4,5].

In the tissue damaging mechanisms polyol pathway was the first discovered mechanism [8]. Then, in the late 1970s, a second mechanism emerged, increased formation of Advanced Glycation End products (AGEs) [9]. In the late 1980s and early 1990s, a third mechanism was elucidated: hyperglycemia-induced activation of protein kinase C (PKC) isoforms [10]. And finally in the late 1990s, latest mechanism was clarified, increased hexosamine pathway flux and consequent over-modification of proteins by N-acetylglucosamine [11].

The Polyol Pathway (Aldose Reductase Enzyme)

Physiological significance of aldose reductase

At present, physiological functions of aldose reductase have not been entirely clarified; its general role in most body tissues is to reduce toxic aldehydes in the cell to inactive alcohols, furthermore, some other specific roles have also been clarified [12]:

Seminal energy production

The polyol pathway was first identified in the seminal vesicle by Hers [12], who demonstrated the conversion of blood glucose into fructose in seminal vesicle as an energy source for sperm cells [12].

Osmo-regulatory function in the kidney

Increased aldose reductase expression and accumulation of intracellular sorbitol in the cultured cell line from rabbit renal papilla as result of elevated extracellular sodium chloride was demonstrated [13]. In the renal medulla, mRNA of the enzyme was profusely expressed compared with relatively low cortex expression [14]. Therefore, these findings denote the osmo-
regulatory role of aldose reductase in the renal homeostasis. Nevertheless, in non-renal cells, aldose reductase physiological osmoregulatory implications is still unknown.

Pathological roles of aldose reductase

Under normoglycemic conditions, through hexokinase pathway, most of the cellular glucose undergoes phosphorylation into glucose 6-phosphate and smaller part of glucose (non-phosphorylated) enters the alternate route of glucose metabolism, the polyl pathway. The rate-limiting step of the polyl pathway is the reduction of glucose to sorbitol by aldose reductase enzyme; sorbitol dehydrogenase enzyme subsequently converts the produced sorbitol to fructose, thus constituting the polyl (sorbitol) pathway. When hexokinase is saturated by ambient glucose (under hyperglycemia), the flux of glucose through the polyl pathway then increased to account for as much as one-third of the total glucose turnover [15].

This leads to accumulation of the products of the polyl pathway that accompanied with depletion in reduced nicotinamide adenine dinucleotide phosphate (NADPH) as well as the oxidized form of nicotinamide adenine dinucleotide (NAD), the cofactors used in the pathway [16], it is significant to mention that NADPH is essential for regeneration of reduced glutathione (critical intracellular antioxidant) and nitric oxide (NO) synthase (NO is important for micro-vascular arrangement and nerve conduction). So, the polyl pathway induces intracellular hyper-osmolar pressure, increases susceptibility to intracellular oxidative stress, elicits micro-vascular derangement and slows the nerve conduction [17,18].

In rats as model, aldose reductase mRNA was highly expressed in the prime target organs of diabetic complications, the lens, the retina, and the sciatic nerve [14]. In the lens, the sorbitol accumulation induces cataract formation due to leakage of amino acids, glutathione, and myo-inositol because of hyperosmotic swelling and derangement of the cell membrane [19]. In the retina of experimental models, the early lesion emerged in vascular component with localization of aldose reductase in retinal microvessels [20-22]. In the nerves, perturbation in the vasculature and metabolic disturbance in the neural cells contributes to the development of diabetic neuropathy [23-25]. In fact, aldose reductase immuno reactivity was found in the paranodal cytoplasm of Schwann cells as well as in pericytes and endothelial cells of endoneurial capillaries [26].

Although insulin treatment effectively delay the onset of long term diabetic complications and slows their progression in patients with insulin-dependent diabetes mellitus (IDDM), it is practically impossible, even with best clinical management available, to maintain normoglycemic state at all times throughout the life of diabetic individuals [27]. Accordingly, chemical agents that effectively halt the hyperglycemic injury in diabetic patients would be of great clinical importance.

Inhibitors of aldose reductase enzyme

Depending on the previous observations, development of many aldose reductase inhibitors as possible therapeutic agents (with diverse chemical structures) for diabetic complications (to prevent retinal damage, cataracts, and nerve damage) became critical. The clinical efficacy of Sorbinil, ponalrestat, and tolrestat (the most studied inhibitors) in diabetic patients has not been fully proved to meet the standards of the Food and Drug Administration [28].

Synthetic aldose reductase inhibitors

Although many synthetic Aldose Reductase Inhibitors such as sorbinil and tolrestat exhibit potent inhibition, their use is now limited (or they have been withdrawn from clinical trials) because of decreased penetration, low efficacy, and safety problems [29-31].

Sorbinil, when diabetic patients without any symptomatic neuropathy were treated with it, significant improvement in the velocity of conduction was observed in all nerves tested (the peroneal motor nerve, the median motor nerve, and the median sensory nerve) [32], because of the difference in the study design, subjects with various degrees of symptomatic neuropathy, and neurophysiological parameters examined as study endpoints, the overall effect turned out to be disappointingly modest [33].

Ponalrestat, another aldose reductase inhibitor of a different chemical structure, with no clinically important adverse reaction observed (c.f. sorbinil), its beneficial effect failed to be proved in randomized controlled study [34], later, it was shown that it didn’t penetrate the human nerve at doses sufficient to decrease the nerve sorbitol levels [35].

Tolrestat, the efficacy of this class of inhibitor was the modest in diabetic patients already symptomatic of neuropathy, the only adverse reaction reported on it was an increase in serum levels of liver enzymes (alanine aminotransferase ALT, aspartate aminotransferase AST), clinical development of tolrestat was withdrawn, due to the inability to demonstrate efficacy on the nerve conduction velocity in the multicenter double-blind studies on diabetic neuropathy [36]. Ranirestat is in Phase III trials in Europe and the US. Its clinical trial began in June 2009. The only available synthetic inhibitor is Epalrestat that is in Japanese market since 1992. So, there is still an urgent need for development of improved Aldose reductase inhibitors [37].

Natural products as potential inhibitors

The benefits of dietary supplements such as naturaceuticals and herbal medicines as pharmaceuticals have gain growing interest due to lack of toxicity and harmful side effects (they are daily consumed). Many structurally diverse phytochemicals and extracts have been reported as potent aldose reductase inhibitors. Naturally occurring compounds with diverse chemical structures (flavonoids, coumarins tannins, alkaloids, terpenoids...
and phenolics) have significant aldose reductase inhibitory activity. Most of the natural sources either terrestrial or marine that contain these compounds are presented in Table 1 & 2.

Table 1: Plant Extracts with aldose reductase inhibitory activity.

| Extract                     | Part Used   | Reference |
|-----------------------------|-------------|-----------|
| 1. Azadirachtaindica, Meliaceae | leaves     | [41]      |
| 2. Aralia elata, Araliaceae  | Cortex      | [42]      |
| 3. Arctiunlappa, Asteraceae  | Ripe fruit  | [43]      |
| 4. Agaricus bisporus, Agaricaceae | Fruiting body | [44] |
| 5. Agaricus blazei, Agaricaceae | Fruiting body | [44] |
| 6. Agrocybe cylindracea, Bolbitiaceae | Fruiting body | [44] |
| 7. Artemisia apiacea, Asteraceae | Whole plant | [45]      |
| 8. Artemisia argyi, Asteraceae | leaves      | [45]      |
| 9. Artemisia capillaris, Asteraceae | Whole plant | [45]      |
| 10. Artemisia iwayomogi, Asteraceae | Whole plant | [45]     |
| 11. Artemisia japonica, Asteraceae | Whole plant | [45]      |
| 12. Artemisia keiskeana, Asteraceae | Whole plant | [45]     |
| 13. Artemisia montana, Asteraceae | Whole plant | [45]      |
| 14. Artemisia princeps, Asteraceae | Whole plant | [45]     |
| 15. Artemisia rubripes, Asteraceae | Whole plant | [45]      |
| 16. Artemisia selengensis, Asteraceae | Whole plant | [45]     |
| 17. Artemisia stolonifera, Asteraceae | Whole plant | [45]      |
| 18. Artemisia sylvatica, Asteraceae | Whole plant | [45]     |
| 19. Adhatodavasica, Acanthaceae | Not Specified | [46] |
| 20. Aegle Aeglemarmelos, Rutaceae | Fruiting body | [46] |
| 21. Biophytum sensittivum, Oxalidaceae | Not Specified | [46] |
| 22. Curcuma longa, Zingiberaceae | rhizome    | [41]      |
| 23. Cuminum cymminum, Lauraceae | Bark        | [47]      |
| 24. Citrus lemon, Rutaceae    | Fruit       | [47]      |
| 25. Citrus sinensis, Rutaceae  | Fruit       | [47]      |
| 26. Cuminum cuminum, Apiaceae  | seeds       | [47]      |
| 27. Caesalpinia odorata, Caesalpiniaceae | Not Specified | [48] |
| 28. Cassia fistula, Caesalpiniaee | Not Specified | [48] |
| 29. Catharanthus roseus, Apocynaceae | leaves     | [48]      |
| 30. Embelia officinalis, Phyllanthaceae | Fruit | [49] |
| 31. Eucalyptus deglupta, Myrtaceae | Not Specified | [50] |
| 32. Eugenia borinquensis, Myrtaceae | Not Specified | [50] |
| 33. Flammulina velutipes, Tricholomataceae | Fruiting body | [51] |
| 34. Foeniculum vulgare, Apiaceae | Seeds       | [47]      |
| 35. Flemingia lineata, Fabaceae | Roots       | [52]      |
| 36. Flemingia macrophylla, Fabaceae | Roots    | [52]      |
| 37. Flemingia prostrata, Fabaceae | Roots     | [52]      |
| 38. Flemingiobrobilfera, Fabaceae | Roots    | [52]      |
| 39. Ficus golmerata, Moraceae | Fruit      | [48]      |
| 40. Gymnemasia sylvestre, Asclepiadaceae | Whole plant | [53] |

How to cite this article: Farid A Badria. Naturceuticals: A New Hope for Treatment of Diabetic Complications. Curre Res Diabetes & Obes J. 2017; 4(2): 555634. DOI: 10.19080/CRDOJ.2017.4.555634
41. Ganoderma lucidum, Ganodermataceae  
Fruiting body  
[51]

42. Grifola frondosa, Polyporaceae  
Fruiting body  
[51]

43. Hericium erinaceus, Hericiaceae  
Fruiting body  
[51]

44. Hypoloma sublateritium, Strophariaceae  
Fruiting body  
[51]

45. Hypsizygus marmoreus, Tricholomataceae  
Fruiting body  
[51]

46. Lentinula edodes, Tricholomataceae  
Fruiting body  
[51]

47. Lyophyllum decastes, Tricholomataceae  
Fruiting body  
[51]

48. Mangifera indica, Anacardiaceae  
Not Specified  
[54]

49. Momordica charantia, Cucurbitaceae  
Fruit  
[47]

50. Morinda citrifolia, Rubiaceae  
Fruit  
[46]

51. Momordica charantia, Cucurbitaceae  
Fruit  
[47]

52. Ocimum sanctum, Lamiaceae  
Leaves  
[46]

53. Psoralea corylifolia, Fabaceae  
Seeds  
[46]

54. Psidium guajava, Myrtaceae  
Fruit  
[47]

55. Piper nigrum, Piperaceae  
Seeds  
[47]

56. Pleurotus ostreatus, Pleurotaceae  
Fruiting body  
[44]

57. Pleurotus erinaceus, Pleurotaceae  
Fruiting body  
[44]

58. Pleurotus comatus, Pleurotaceae  
Fruiting body  
[44]

59. Pholiota nameko, Strophariaceae  
Fruiting body  
[44]

60. Panellus serotinus, Tricholomataceae  
Fruiting body  
[44]

61. Spinacea oleacea, Amaranthaceae  
Seeds  
[44]

62. Syzygium malaccense, Myrtaceae  
Not Specified  
[54]

63. Tribulusterrestris, Zygophyllaceae  
Fruit  
[46]

64. Tinospora cordifolia, Menispermaceae  
Stem  
[46]

65. Trigone fennigrugaceum, Trigonaceae  
Seeds  
[47]

66. Trachyspermum ammi, Apiaceae  
Seeds  
[47]

67. Vaccinium myrtillus, Ericaceae  
Not Specified  
[54]

68. Withania somnifera, Solanaceae  
Root  
[41]

Table 2: Marine sources of aldose reductase inhibitors.

1. Dysideasp  
[55]

2. Irciniaramosa  
[55]

3. Dactylospongiametachromia  
[55]

4. 5.  

6. Asparagopsis taxiformis  
[57]

7. Dictyodendrillasp  
[57]

8. Ecklonia cave  
[58]

From natural sources that have been reported, Flavonoids and related compounds is the most widely studied natural product family with inhibitory activity. Vitamin C is one of the natural products that entered clinical trials, which showed 81% of in-vitro inhibition [38]. Vitamin C as dietary supplement seems to be effective in decreasing accumulation of erythrocyte’s sorbitol and improves endothelium-dependent vasodilatation in diabetic patients [38-40].

Conclusion

Worldwide, researcher and scientists are widely interested in prevention of diabetic complications. Use of naturally occurring compounds in the treatment of variety of chronic disorders and illnesses is growing, and many extracts and isolated compounds are becoming better alternatives to synthetic drugs [41-58], diabetes and its complications can be prevented and/or decreased using these natural molecules. Quercetin Kaempferol and Ellagic acid is promising naturally occurring compounds that have evidences since a period for their aldose reductase inhibitory activity.

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