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Review Article

Camel milk as a potential therapy for controlling diabetes and its complications: A review of *in vivo* studies

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ABSTRACT

Diabetes is a condition in which there is an elevation of blood glucose. Insulin, which is produced by the pancreas, is an important hormone needed by the body because it enables glucose to be transported into cells. Under the diabetic condition, the cells may not respond properly to insulin or the body does not produce a sufficient amount of insulin, or both. This situation will cause glucose accumulation in the blood that leads to major complications. Oral insulin therapy has been used for many years; however, coagulation in an acidic environment decreases the efficacy of insulin by neutralizing its actions. Several researchers have found that camel milk can be an adjunct to insulin therapy. It appears to be safe and effective in improving long-term glycemic control. Therefore, the aim of this study was to review *in vivo* studies on the effect of camel milk as a potential therapy for controlling diabetes and its complications such as high cholesterol levels, liver and kidney disease, decreased oxidative stress, and delayed wound healing.

1. Introduction

Diabetes mellitus (DM) is a disease characterized by a high level of blood sugar (i.e., glucose) that results from the failure of the body to produce sufficient insulin (type 1 diabetes) or from the inability to respond properly to the insulin that has been produced by the pancreas (type 2 diabetes) [1]. The global prevalence of DM for all age groups was estimated at 2.8% in 2000, and is expected to rise to 4.4% in 2030 [2]. A major part of this increase is expected to occur in Third World countries with the number of diabetics increasing to 35% in 2025 among those aged 20 years or older. Hyperglycemia is a metabolic disorder (i.e., the circulating blood glucose level is excessive in the blood plasma) that results from defects in insulin secretion, insulin action, or both. The function of insulin is to lower the level of blood glucose, which occurs especially after eating. Chronic hyperglycemia is associated with long-term damage and with the dysfunction and failure of various organs—especially the eyes, heart, nerves, kidneys, and blood vessels; it is linked with hypertension [3]. However, metabolic control can be improved through diet and physical activity with or without antidiabetes drugs, which significantly decrease the risk of complications [4].

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Camel milk achieves the nutritional requirements of the minor population in harsh and arid parts of Africa and Asia. It is common practice in these regions to recommend the consumption of camel milk in its fresh state or its sour state [5] for the general treatment of diabetes [6]. It is different from the milks of other ruminants in that it does not form coagulum in an acidic environment [7]. This is attributed to the low degree of phosphorylation of the caseins in camel milk [5,7]. From a nutritional point of view, camel milk has a low cholesterol content and its fat primarily consists of polyunsaturated fatty acids that are completely homogenized and gives the milk a smooth white appearance [6]. The lactose in camels milk exists in concentrations of 4.8%, but this milk sugar is surprisingly easily metabolized by people who have lactose intolerance [8]. A possible explanation for this is that camel milk produces less casomorphin, which provokes less intestinal motility; this would cause lactose to be more exposed to the action of lactase [9]. Camel milk contains a low amount of β-lactoglobulin [10,11] and β-casein [11]. Because these two protein components are responsible for allergies, camel milk has little or no allergic effects [12]. Furthermore, camel milk has higher antibacterial and antiviral properties than cow milk. This is partially because of the higher concentration of lactoferrin in camel milk (220 mg/L) than in cow milk (110 mg/L) and the higher concentration of lysozyme in camel milk (288 μg/100 mL) than in cow milk (13 μg/100 mL) [12–14]. In addition, camel milk has a higher level of lactoperoxidase, immunoglobulin G, and secretory immunoglobulin A with antimicrobial activity [12–14], and higher vitamin C content [15,16]. Various research studies have been performed to examine the efficiency of camel milk to treat diabetes. The objective of this research was to review *in vivo* studies on the effect of camel milk as a potential therapy for controlling diabetes (type 1) and its complications such as high cholesterol level, liver and kidney disease, decreased oxidative stress, and delayed wound healing.

2. Antihyperglycemic effect of camel milk

Diabetes mellitus is a serious disease with multiple complications that is rising dramatically worldwide. Three-fourths of the world population cannot afford allopathic medicine and thus has to rely on naturopathic medicine, which is basically derived from natural products of animals and plants [17]. Once diabetic patients start insulin therapy, they have to take it permanently and usually insulin dose continue to increase as time progresses. Clinical research on the use of camel milk by patients with type 1 diabetes has indicated that drinking camel milk daily decreases the blood glucose level and reduces insulin requirement by 30% [18]. It appears that camel milk provides an insulin-like protein in a different form than in other mammals and/or delivers some other therapeutic compounds that boosts the health of diabetic patients. However, the mechanism is not yet fully understood. Mucosal surfaces are a common and suitable route for delivering drugs such as peptides and proteins to the body. However, the oral administration of insulin is incapable of overcoming mucosal barriers and is degraded by digestive enzymes before it enters the bloodstream [19]. As a unique feature of camel milk, the insulin-like protein could be protected in the stomach and absorbed efficiently into blood stream to reach the target. This is because camel milk does not coagulate in an acidic environment and it has a higher buffering capacity than the milk of other ruminants [13]. In addition, since no differences noted in the sequence of camel milk insulin-like protein and its digestion pattern compared to other sources of milk to overcome the mucosal barriers, camel milk insulin-like protein could be protected in the stomach by nanoparticles (e.g., lipid vesicles) to reach the target [20]. Camel milk also contains approximately 52 micro unit/ml of insulin-like protein compared to cow milk (16.32 micro unit/ml) which mimic insulin interaction with its receptor, and it has a higher content of zinc [21] which has a key role in insulin secretory activity in pancreatic beta cells. Beg et al [22] found that the amino acid sequence of some camel milk protein is rich in half cystine, which has a superficial similarity with the insulin family of peptides. In addition, compared to milk from other mammalian species, camel milk possesses a different casein content, a higher amount of polyunsaturated fatty acids (C18:1–C18:3), larger lipid micelles, and a higher amount of vitamin B_3 [23,24]. Furthermore, the small size and weight of camel milk immunoglobulin may offer enormous potential through interaction with the host cell protein and cause an induction of regulatory cells and finally result in a downward regulation of the immune system and β-cell salvage [18,25]. Some researchers suggest that the insulin-like protein in camel milk has the ability to resist proteolytic digestion, which makes its absorption into circulation faster than insulin-like protein from other milk sources (Fig. 1).

A previous study shows that raw camel milk has the ability to reduce blood glucose level by 55% in diabetic rats, compared to raw cattle milk (43%) [15]. Agrawal et al [26] studied the hypoglycemic activity of raw and pasteurized camel milk in streptozotocin (STZ)-induced diabetic rats. Based on the results, the blood glucose levels in diabetic rats treated with raw camel milk decreased from 169.68 ± 28.7 mg/dL to 81.54 ± 11.4 mg/dL ($p < 0.02$) after 4 weeks of treatment, whereas diabetic rats treated with pasteurized camel milk showed a slight decrease from 135.45 ± 20.91 mg/dL to 113 ± 29.09 mg/dL (Table 1) [13,14,26–30]. A new study was conducted by Sboui et al [27] to evaluate the effect of camel milk administered for 5 weeks to alloxan-induced diabetic dogs. A significant reduction in the level of blood glucose from 10.88 ± 0.55 mmol/L to 5.77 ± 0.44 mmol/L occurred in dogs treated with 500 mL of camel milk for 5 weeks (Table 1). The effect of camel milk in comparison with biosynthetic insulin treatment in experimentally induced diabetes in rabbits was investigated by El-Said et al [14]. They found that the mean serum insulin level was significantly higher (7.9 ± 0.9 μIU/mL) for diabetic rabbits treated with camel milk for 4 weeks than for untreated diabetic rabbits and insulin-treated diabetic rabbits (2.4 ± 0.1 μIU/mL and 5.6 ± 0.4 μIU/mL, respectively). In diabetic rabbits, treatment with camel milk was able to lower the glucose level more greatly than biosynthetic insulin (Table 1). Al-Numair et al [28] report the antihyperglycemic effect of camel milk on STZ-induced diabetic rats. They found that STZ-diabetic rats that were fed camel milk at the optimum dose of 250 mL/d for 45 days showed a significant