Beneficial Effect of *Cissus quadrangularis* Linn. on Osteopenia Associated with Streptozotocin-Induced Type 1 Diabetes Mellitus in Male Wistar Rats

Srinivasa Rao Sirasanagandla, Sreedhara Ranganath Pai Karkala, Bhagath Kumar Potu, and Kumar M.R. Bhat

1 Department of Anatomy, Melaka Manipal Medical College, Manipal University, Madhav Nagar, Manipal, Karnataka 576104, India
2 Department of Pharmacology, Manipal College of Pharmaceutical Sciences, Manipal University, Manipal, Karnataka 576104, India
3 Department of Anatomy, College of Medicine and Medical Sciences, Arabian Gulf University, P.O. Box 26671, Bahrain
4 Department of Anatomy, Kasturba Medical College, Manipal University, Manipal, Karnataka 576104, India

Correspondence should be addressed to Kumar M.R. Bhat; kummigames@yahoo.com

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Petroleum ether fraction of *Cissus quadrangularis* (PECQ) impact on the development of osteopenia in type 1 diabetic rat model has been evaluated. Diabetic rats were treated orally with two doses of PECQ. Another group of diabetic rats were treated with subcutaneous injection of synthetic human insulin. The cortical and trabecular bone thickness and bone strength were significantly decreased in diabetic rats. Treatment with two doses of PECQ significantly prevented these changes in diabetic rats. However, PECQ treatment (two doses) did not alter the glycermic levels in these diabetic rats. Increased levels of serum alkaline phosphatase (ALP), tartrate-resistant acid phosphatase (TRAP), and hydroxyproline were noted in diabetic rats when compared to normal control rats. The two doses of PECQ treatment further improved the serum ALP levels and significantly decreased the serum levels of TRAP and hydroxyproline. The effects of PECQ treatment on histological, biomechanical, and biochemical parameters are comparable to those of insulin. Since PECQ improves the bone health in hyperglycemic conditions by enhancing the cortical and trabecular bone growth and altering the circulating bone markers, it could be used as an effective therapy against diabetes-associated bone disorders.

1. Introduction

Diabetes mellitus (DM) is a combination of metabolic disorders characterized by impaired metabolism of carbohydrates, proteins, and fat resulting from insulin deficiency [1]. Skeletal disorders are common in diabetic patients, namely, reduced bone mineral content [2, 3], deranged calcium and phosphate levels, and altered bone metabolism [3–6]. Osteopenia [7], increased risk of fractures [8], and delayed fracture healing [9] are evident in these patients. Earlier, animal models have proved the association between osteopenic/osteoporotic changes and type 1 DM [10–15]. It has been demonstrated that the adverse effects of DM on bone tissue could be due to insulinopenia, bone microangiopathy, impaired regulation of mineral metabolism, and alterations in local factors that regulate bone remodeling [16, 17]. Dimensions of the femur such as weight, length, and diaphyseal width were found to be decreased in diabetic rats [18]. Furthermore, experimental studies have demonstrated that the mechanical strength of bones is reduced in diabetic rats [19–21]. Diabetes is also found to delay fracture healing and treatment with synthetic calcium phosphate or hydroxyapatite has been shown to have a positive effect on fracture healing [22–24]. It was also shown that the treatment with either insulin or 17-b estradiol (E2) can reverse the altered architecture of bones in diabetic rats and their effects were found to be similar [25]. Verhaeghe et al. have observed the positive effect of E2 against the metaphyseal trabecular bone damage in ovariectomized...
diabetic rats, when compared to nontreated control rats [26].

Cissus quadrangularis (CQ) is a climbing shrub, which belongs to the Vitaceae family. It is usually seen in hot climate in various states of India, Sri Lanka, Malaya, Java, and West Africa [27]. In Ayurveda, its usage in the treatment of bone fractures and swelling has been mentioned [28]. CQ has been shown to have an ability to accelerate the healing of bone fracture [29]. Experimental animal models have proved the antosteoporotic potential of ethanol, petroleum ether, and hexane fractions of the CQ [27, 30, 31]. A pharmacological study on CQ has shown the presence of phytoestrogen steroids [32]. Recently, the phytoestrogen-rich fraction separated from the CQ has been shown to have potent antosteoporotic activity [33]. In vitro study has shown that the petroleum ether fraction of CQ (PECQ) enhances the proliferation and differentiation of rat bone marrow mesenchymal stem cells [34]. Previously in our laboratory, the protective effect of PECQ on defective fetal skeletal ossification in maternal diabetes has been studied (ahead of print). Though the pharmacological effect of CQ on bone health has been studied extensively, no attempt has been made to study the efficacy of CQ on osteopenia associated with DM. In the presented study, we evaluated the effect of CQ against bone histology, biomechanical changes, and circulating bone markers in type 1 diabetic rats.

2. Material and Methods

2.1. Preparation of Plant Extract. The fresh stems of CQ were air-dried and ground into powder. Using a soxhlet apparatus, 1.3 kg CQ powder was subjected to extraction with 95% ethyl alcohol. The ethanol extract obtained (125 g) was further suspended in water. Then, it was partitioned with petroleum ether, and hexane fractions of the CQ [27, 30, 31]. A pharmacological study on CQ has shown the presence of phytoestrogen steroids [32]. Recently, the phytoestrogen-rich fraction separated from the CQ has been shown to have potent antosteoporotic activity [33]. In vitro study has shown that the petroleum ether fraction of CQ (PECQ) enhances the proliferation and differentiation of rat bone marrow mesenchymal stem cells [34]. Previously in our laboratory, the protective effect of PECQ on defective fetal skeletal ossification in maternal diabetes has been studied (ahead of print). Though the pharmacological effect of CQ on bone health has been studied extensively, no attempt has been made to study the efficacy of CQ on osteopenia associated with DM. In the presented study, we evaluated the effect of CQ against bone histology, biomechanical changes, and circulating bone markers in type 1 diabetic rats.

2.2. Animals. In the present study, 3-month-old male Wistar rats (180–220 g weight) were used. After obtaining approval from the Institutional Animal Ethical Committee, rats were placed in the Central animal research facility of Manipal University according to guidelines of the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA). Proper ventilation with temperature control was maintained on a 12 hr dark and 12 hr light schedule throughout the experiment. Rats were fed a standard balanced diet and water.

2.3. Induction of Diabetes and Treatments. After one week male Wistar rats were induced diabetes with streptozotocin (STZ) injection intraperitoneally (40 mg/kg body weight), which was dissolved in 0.1 M citrate buffer, pH 4.5. Control rats were injected 0.1 M citrate buffer. The blood glucose levels were analyzed seven days after injection using Glucometer (AccuChek Active). Animals demonstrating hyperglycemia (>250 mg/dL) were treated orally with PECQ at daily doses of 500 mg/kg and 750 mg/kg body weight. The dose was selected based on the previous study [30]. The diabetic rats in another group were injected subcutaneously twice daily with human synthetic insulin (INS) (Actrapid, Novo Nordisk India Pvt. Ltd., India), at a dose of 10 U/kg body weight. Treatment continued for 45 days.

2.4. Experimental Design. Experimental rats (n = 30) were allocated to 5 groups each containing 6 rats. Rats in normal control (NC) Group A received 0.5% CMC; Group B, diabetic control group (DC), received 0.5% CMC; Group C, the diabetic + CQ1 group (DC + CQ1), received 500 mg/kg body weight dose of PECQ; Group D, the diabetic + CQ2 group (DC + CQ2), received 750 mg/kg body weight dose of PECQ; and Group E, the diabetic + INS group (DC + INS), rats received INS. The blood glucose levels were analyzed at regular intervals of the experimental period. Following the completion of experiment, the animals were sacrificed under anesthesia by cervical dislocation. Before sacrificing the animals, blood was collected for estimation of serum ALP, TRAP, and hydroxyproline. Right femora were collected for histomorphometrical analysis of trabecular bone and cortical bone. Left femora were stored at −70°C for testing the biomechanical properties. Right tibia was collected for measuring the dry weight.

2.5. Histomorphometrical Analysis. Left femora were dissected and the soft tissue separated. Tissues were fixed in the PLP fixative for 24 hr at 4°C. Then, the femora were subjected to decalcification using EDTA-glycerine solution. After 20 days of complete decalcification, tissues were dehydrated and placed in paraffin wax. The longitudinal sections (5 μm thickness) of the lower end of the femur were taken on rotary microtome and then processed for eosin and hematoxylin staining. The stained sections were used for analysis of the thickness of trabecular bone in the metaphyseal and epiphyseal regions, by using Olympus CellSens Imaging Software (1.6 version, USA).

2.6. Measurement of Biomechanical Properties. The maximum flexor load was measured by a three-point bending test, using a Universal testing 3366 machine (Instron Corp, UK). Briefly, the left femora were brought to room temperature from −70°C and wiped with tissue paper. In the material testing machine, the bone was placed horizontally on two supports and load was applied in the middle of the shaft, at a speed of 5 mm/min until the bone was fractured.

2.7. Biochemical Analysis of Serum Bone Markers. ALP and TRAP levels were estimated by spectrophotometric method, using commercially available kits (Agappe diagnostics). Serum hydroxyproline levels were analyzed by Neuman and Logan method [35].

2.8. Dry Weight of the Tibia. Right tibia were collected and dissected free of soft tissue. Bone tissues were kept in a hot-air oven at 110°C for 48 hr and were weighed in digital balance as described previously [36].
Table 1: Effect of PECQ on blood glucose levels (mg/dL) in diabetic rats.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Day 0</th>
<th>Day 5</th>
<th>Day 15</th>
<th>Day 25</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>89 ± 5.71</td>
<td>97.16 ± 5.02</td>
<td>92.5 ± 3.51</td>
<td>95.5 ± 4.58</td>
<td>99.83 ± 4.86</td>
<td>105.33 ± 5.14</td>
</tr>
<tr>
<td>DC</td>
<td>294.5 ± 9.66***</td>
<td>351.16 ± 23.5***</td>
<td>390 ± 18.44***</td>
<td>394 ± 19.52***</td>
<td>398 ± 26.51***</td>
<td>381 ± 21.59***</td>
</tr>
<tr>
<td>DC + CQ1</td>
<td>305 ± 13.8</td>
<td>342.66 ± 21.12</td>
<td>374.5 ± 14.49</td>
<td>379.5 ± 19.97</td>
<td>372.83 ± 23.65</td>
<td>375 ± 25.91</td>
</tr>
<tr>
<td>DC + CQ2</td>
<td>308.66 ± 13.48</td>
<td>346.33 ± 14.25</td>
<td>364.66 ± 22.08</td>
<td>365 ± 19.91</td>
<td>379 ± 26.61</td>
<td>378.5 ± 17.49</td>
</tr>
<tr>
<td>DC + INS</td>
<td>292.66 ± 9.05</td>
<td>102.83 ± 6.35***</td>
<td>109.5 ± 6.14**</td>
<td>99.16 ± 4.63**</td>
<td>117.16 ± 5.31**</td>
<td>103.83 ± 6.1**</td>
</tr>
</tbody>
</table>

***P < 0.001 when compared to NC group. $P < 0.001$ when compared to DC group.

2.9. Statistical Analysis. Results were expressed as the mean ± standard error of mean. Data was analyzed by using Graphpad Prism (version 5.1). One-way ANOVA followed by Bonferroni’s multiple comparison test was used to evaluate differences between groups. Statistical significance was considered at $P < 0.05$.

3. Results

3.1. Effect of PECQ on Blood Glucose Levels. DC rats had hyperglycemia (>250 mg/dL) throughout the experiment. The two doses of PECQ treatment did not alter the blood glucose levels in diabetic rats when compared to diabetic nontreated rats ($P > 0.05$; Table 1). However, insulin treatment significantly decreased the blood glucose levels, when compared to DC group ($P < 0.001$; Table 1).

3.2. Effect of PECQ on Trabecular Bone in Epiphyseal Region. DC rats had thinner trabeculae in the epiphyseal region ($P < 0.001$; Figures 1(a) and 1(b)) when compared to NC rats suggesting that the hyperglycemia affects the normal bone architecture and leads to bone loss in the epiphyseal region. Treatment with PECQ significantly improved the trabecular bone thickness in the DC + CQ1 ($P < 0.01$; Figures 1(a) and 1(b)) and DC + CQ2 ($P < 0.001$; Figures 1(a) and 1(b)) groups when compared to DC rats. On the other hand, metabolic control with INS significantly prevented the bone loss in diabetic rats ($P < 0.001$; Figures 1(a) and 1(b)) when compared to DC rats.

3.3. Effect of PECQ on Trabecular Bone in Metaphyseal Region. Thinner trabeculae were observed in the DC rats ($P < 0.001$; Figures 2(a) and 2(b)) when compared to NC rats, suggesting that hyperglycemia also affects the bone growth in the metaphyseal region. Treatment with two doses of PECQ significantly improved the trabecular bone thickness in DC + CQ1 and DC + CQ2 groups ($P < 0.01$; Figures 2(a) and 2(b)) when compared to diabetic nontreated rats. INS treatment also significantly improved the bone thickness in DC + INS rats ($P < 0.001$; Figures 2(a) and 2(b)) when compared to diabetic nontreated rats.

3.4. Effect of PECQ on Cortical Bone. The thickness of cortical bone significantly decreased in the DC group ($P < 0.001$; Figures 3(a) and 3(b)) when compared to NC rats, indicating the effect of hyperglycemia on cortical bone loss. PECQ treatment significantly improved the cortical bone thickness in the DC + CQ1 ($P < 0.001$), DC + CQ2 ($P < 0.001$), and DC + INS ($P < 0.001$) groups when compared to DC rats (Figure 4).

3.5. Effect of PECQ on Mechanical Strength. Mean maximum flexor load (N) required to produce break in the femur of NC, DC, DC + CQ1, DC + CQ2, and DC + INS groups was $96.53 ± 5.37$, $53.2 ± 5.03$, $76.47 ± 4.4$, $81.42 ± 6.24$, and $91.53 ± 4.79$ newtons, respectively. Mean maximum flexor load was significantly less in the diabetic nontreated rats ($P < 0.01$; Figure 4), when compared to nondiabetic control rats. Further, mean maximum flexor load was significantly more in DC + CQ1 ($P < 0.01$; Figures 3(a) and 3(b)) when compared to diabetic nontreated rats.

3.6. Effect of PECQ on Dry Weight of Tibia. Dry weight of the tibia measured in NC, DC, DC + CQ1, DC + CQ2, and DC + INS groups was $0.42 ± 0.019$, $0.26 ± 0.017$, $0.35 ± 0.013$, $0.36 ± 0.021$, and $0.39 ± 0.022$ grams, respectively. Bone weight was significantly decreased in the DC rats ($P < 0.001$; Figure 5), when compared to NC rats. Dry weight was significantly increased in all the treated groups, DC + CQ1 ($P < 0.05$), DC + CQ2 ($P < 0.05$), and DC + INS ($P < 0.001$), when compared to DC rats (Figure 5).

3.7. Effect of PECQ on ALP, TRAP, and Hydroxyproline. Serum ALP levels were significantly increased in diabetic nontreated animals ($P < 0.001$; Table 2) when compared to NC group. Increased ALP levels confirm that diabetes induces bone damage. Serum ALP levels further increased in the DC + CQ1 ($P < 0.01$; Figures 3(a) and 3(b)) and DC + CQ2 ($P < 0.001$; Figures 3(a) and 3(b)) when compared to diabetic nontreated rats.

Table 2: Effects of PECQ on serum bone markers in diabetic rats.

<table>
<thead>
<tr>
<th>Groups</th>
<th>ALP (U/L)</th>
<th>TRP (U/L)</th>
<th>Hydroxyproline (μg/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>$96.45 ± 5.93$</td>
<td>$6.40 ± 0.29$</td>
<td>$0.233 ± 0.008$</td>
</tr>
<tr>
<td>DC</td>
<td>$188.7 ± 7.02$***</td>
<td>$8.52 ± 0.19$***</td>
<td>$0.285 ± 0.007$**</td>
</tr>
<tr>
<td>DC + CQ1</td>
<td>$217.3 ± 9.4$***</td>
<td>$6.90 ± 0.24$A</td>
<td>$0.250 ± 0.007$A</td>
</tr>
<tr>
<td>DC + CQ2</td>
<td>$223.3 ± 13.21$***</td>
<td>$6.74 ± 0.40$B</td>
<td>$0.249 ± 0.009$B</td>
</tr>
<tr>
<td>DC + INS</td>
<td>$229.1 ± 9.75$**</td>
<td>$6.57 ± 0.37$**</td>
<td>$0.239 ± 0.009$**</td>
</tr>
</tbody>
</table>

***P < 0.001, **P < 0.01 when compared to NC group. $P < 0.01$, $P < 0.05$ when compared to DC group.
in DC + CQ1 ($P < 0.001$), DC + CQ2 ($P < 0.001$), and DC + INS ($P < 0.001$) groups when compared to NC group (Table 2). This result shows that both PECQ and metabolic control with INS enhance the bone formation and mineralization process in hyperglycemic conditions. When compared to NC group, serum levels of TRAP ($P < 0.001$; Table 2) and hydroxyproline ($P < 0.01$; Table 2) were significantly increased in diabetic rats. Serum TRAP is a biomarker of osteoclast activity and hydroxyproline is considered as an end product of collagen degradation. The increased levels of these two proteins indicate the excessive bone resorption in the diabetic rats. Further, all the treatments significantly decreased the serum TRAP activity in the DC + CQ1 ($P < 0.05$), DC + CQ2 ($P < 0.01$), and DC + INS ($P < 0.01$) groups in comparison to diabetic nontreated rats (Table 2). Similarly, the hydroxyproline levels were also significantly decreased in the DC + CQ1 ($P < 0.05$), DC + CQ2 ($P < 0.05$), and DC + INS ($P < 0.01$) groups in comparison to DC group (Table 2).

4. Discussion

Results of the present study showed that PECQ treatment is effective against type 1 DM- induced histological, biomechanical, and biochemical changes in the bone. Further, these
results are comparable to the effects of insulin treatment. Unlike insulin, PECQ did not reduce the blood glucose levels in the diabetic rats indicating that PECQ has shown its effect through mechanisms other than the glycemic control.

The association between type 1 DM and osteoporosis has been accepted widely both experimentally [37, 38] and clinically [16, 39]. Based on the existing data, it is uncertain that reduced bone mass in diabetic rats is either due to defective bone formation or due to reduced bone growth [40]. Previous studies have reported the histological changes in both cortical bone [13, 41, 42] and trabecular bone [43, 44] in diabetic animals. Our results are consistent with those of earlier studies wherein the diabetic rats showed a marked reduction in the thickness of both cortical and trabecular bones. The diabetic rats also had decreased dry weight of the bone compared to healthy animals. Bone strength depends on the integrity of the two components of bone: cortical and trabecular bone. Previous studies on the effect of diabetes on bone strength have reported conflicting data. In few reports bone strength is increased [20, 21]; meanwhile it is reduced in others [13, 42]. Our results indicate that diabetic rats seem to have lower bone strength.

It has been hypothesized that inflammation plays a role in the pathology of diabetes-induced bone complications [45]. Cytokines such as IL-6, IL-1β, and TNF-α are known for their involvement in the process of bone loss in diabetes.
Figure 3: (a) Effect of PECQ on mean thickness of cortical bone. Thickness of the cortical bone significantly decreased in diabetic control (DC) rats when compared to normal control (NC) rats. Treatment with two different doses of PECQ (DC + CQ1 and DC + CQ2) or with insulin (DC + INS) significantly increased the bone thickness in diabetic rats when compared to nontreated diabetic rats. ***P < 0.001 when compared to NC group; **P < 0.001, *P < 0.01 when compared to DC group. (b) Photomicrographs of cortical bone. Thickness of the cortical bone was significantly less in the diabetic control group (DC) when compared to normal control group (NC). Further treatment with two doses of the PECQ (DC + CQ1, DC + CQ2) and insulin (DC + INS) improved the cortical bone growth. C: cortical bone; M: medullary cavity; H and E staining, scale bar: 200 μm.

[46]. LT-β, IL-6, IFN-γ, and TNF-α were found to increase in the diabetic bone [45]. Anti-inflammatory activity of CQ has been shown by previous studies [47, 48]. Ethanol fraction of CQ has been shown to decrease the serum levels of the proinflammatory cytokines TNF-α, IL-1β, and IL-6 in ovariectomized mice [48]. The positive effect of PECQ on bone loss in the diabetic state could be due to its anti-inflammatory property. However, experimental evidence is required to confirm effect of PECQ on both bone and serum cytokines levels in diabetic state.

Hyperglycemia is known to alter the antioxidant defense by increasing the polyol pathway flux, rate of formation of the ROS, and glucose-derived advanced glycosylation end products [49]. Previous studies have confirmed the association between oxidative stress and the development of osteopenia in DM [50, 51]. ROS is known to stimulate bone resorption by altering the function of osteoclasts [52]. Bai et al., have observed that oxidative stress can inhibit the differentiation of osteoblast cells [53]. Previous studies have demonstrated antioxidant and free radical scavenging potential of CQ both in vitro and in vivo [54, 55]. Hence, beneficial effects of PECQ against bone damage in diabetic rats can be correlated to its antioxidant properties.

Endocrine factor such as insulin-like growth factor-1 (IGF-1) signaling is found to be downregulated in both humans and animal models with type I DM [56, 57].
**5. Conclusion**

Preliminary results of the present study indicate that **PECQ** is effective in improving histological, biomechanical, and biochemical changes of bone in diabetic rats. Though exact mechanism of action of **PECQ** has not been ascertained, the observed effect of **PECQ** could be due to its osteogenic, antioxidant, and anti-inflammatory properties.
However, in this context, extensive studies are required to confer the exact mechanism of PECQ on bone cells in hyperglycemic conditions.

**Conflict of Interests**

The authors declare that there is no conflict of interests regarding the publication of this paper.

**References**


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