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Quercetin lowers plasma uric acid in pre-hyperuricemic males: a randomized, double-blinded, placebo-controlled, cross-over trial

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Running Head: Quercetin lowers uric acid in humans

Key words: quercetin, bioequivalence, dietary supplement, human

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Key words: quercetin, hyperuricemia, uric acid, fasting glucose, blood pressure, clinical trial
Abstract

Background: Elevated plasma uric acid is a risk factor for gout, insulin resistance and type 2 diabetes. Quercetin, a flavonoid found at high levels in onions, tea and apples, inhibits xanthine oxidoreductase in vitro, the final step in intracellular uric acid production, indicating that quercetin might be able to lower blood uric acid in humans.

Objective: We determined the effects of 4 wk oral supplementation of quercetin on plasma uric acid, blood pressure and fasting glucose.

Design: This randomized, double-blinded, placebo-controlled, cross-over trial recruited 22 healthy males (19-60 y) with baseline plasma uric acid concentration in the higher, but still considered healthy, range (339±51 µmol/L). Intervention was one tablet containing 500 mg quercetin daily for 4 wk, compared to placebo, with a 4-wk washout period between treatments. Primary outcome was change in concentration of plasma uric acid after 2 and 4 wk. Secondary outcome measures were changes in fasting plasma glucose, 24-hour urinary excretion of uric acid and resting blood pressure.

Results: After quercetin treatment, plasma uric acid concentrations were significantly lowered by -26.5 µmol/L (95% confidence interval [CI], -7.6 to -45.5; \( P=0.008 \)), without affecting fasting glucose, urinary excretion of uric acid or blood pressure.

Conclusions: Daily supplementation of 500 mg quercetin, containing the bioavailable amount of quercetin as present in ~100 g red onions, for 4 wk, significantly reduces elevated plasma uric acid concentrations in healthy males.
High blood uric acid (hyperuricemia) is the strongest determinant risk factor for gout, an inflammatory arthritis caused by uric acid crystals, and is higher in males compared to females. Hyperuricemia is also common in patients who develop diabetes, obesity, hyperglycaemia, hypertension, and stroke, although it is often unattended until their first, if any, gout attack. Gout prevalence increased from ~0.5 to ~3% between 1960 and 2010 in the US and other areas, accompanied by a parallel increase in the number of individuals with hyperuricemia. The fact that 25-34 is the age group with the highest blood uric acid level may suggest that hyperuricemia precedes the development of metabolic syndromes. Interestingly, allopurinol, a uric acid lowering agent used in gout therapy, has a protective effect on hypertension, which suggests that excess uric acid synthesis is a causal factor in developing hypertension.

Some dietary factors, including purines, alcohol and fructose, also elevate blood uric acid. For example, chronic exposure to fructose can lead to development of hyperuricemia. Fructose phosphorylation by fructokinase causes intracellular phosphate depletion leading to the activation of deaminase, which converts adenosine monophosphate to inosine monophosphate. The consumption of ATP activates transformation of inosine monophosphate to inosine, the precursor of uric acid metabolism. Chronic hyperuricemia may also up-regulate fructokinase expression, leading to the amplification of the lipogenic effects of fructose in human hepatocytes. Xanthine oxidoreductase (also called xanthine oxidase or xanthine dehydrogenase depending on proteolytic processing) catalyses the final step in uric acid production. Inhibition of this enzyme has been a target for uric acid-lowering drugs, such as allopurinol. Studies in both healthy humans and in animal
models\(^\text{24}\) substantiate the importance of increased insulin resistance to hyperuricemia, and \textit{vice versa}, providing a link to excess fructose intake.

Quercetin is a dietary flavonoid which is particularly abundant in onion, black tea and apples, and occurs predominantly as quercetin 4’-\textit{O}-glucoside or quercetin-3,4’-\textit{O}-diglucoside in onions and quercetin 3-\textit{O}-rutinoside in tea\(^\text{25}\). The bioavailability of quercetin in humans has been extensively studied, and in plasma, multiple conjugates of quercetin appear post-prandially. In healthy subjects, using urine as a biomarker, we have previously demonstrated that 500 mg quercetin aglycone, as provided in supplements used here, is comparable to the quercetin present in \(~100\) g of fresh red onion\(^\text{26}\). Quercetin, and its metabolites, inhibit xanthine oxidoreductase \textit{in vitro}\(^\text{27}\) and regulate blood uric acid level \textit{in vivo} in animal studies\(^{28; 29; 30}\), yet whether uric acid metabolism could be similarly affected in humans is still highly debatable\(^{31; 32; 33; 34; 35; 36}\).

Therefore, we performed this randomized, double-blinded, placebo-controlled, cross-over trial to test the hypothesis that 4 wk of quercetin supplementation might result in a reduction in plasma uric acid in \textbf{male} subjects with non-optimal blood uric acid.
Subjects and methods

Subjects

22 healthy males were eligibly assigned and successfully compliant to the complete study. Selection criteria included being apparently healthy, age between 19 and 65, BMI between 18.5 and 29.9 kg/m², non-smoking and not a heavy drinker (less than 3 units of alcohol regularly per day). Volunteers with diagnosed gout and/or kidney stone, who were experiencing intestinal disorders, or whose plasma uric acid concentration was lower than 300 µmol/L, were excluded. All data were collected from February 2013 to April 2014 and analysed in the School of Food Science and Nutrition at the University of Leeds, UK. The study was conducted according to the guidelines laid down in the declaration of Helsinki of 1975 as revised in 1983 and all procedures involving human subjects were approved by the University of Leeds, MaPS and Engineering joint Faculty Research Ethics Committee (MEEC12-019), UK. Written informed consent was obtained from each of the subjects before commencement of the study.

Study design

The main goal and primary objective of the present study was to examine the chronic effect of quercetin on plasma uric acid concentration. For this purpose, the study was a randomized, double-blinded, placebo-controlled, cross-over, 4-wk intervention trial with 2 treatment groups, with daily consumption of either quercetin dihydrate in a tablet form (500 mg stated on the label, actual measured 544±45 mg quercetin dihydrate aglycone, purchased from Nature’s Best, Kent, UK, and containing small amounts of calcium carbonate, cellulose, methylcellulose, glycerine, stearic acid, silicon dioxide, crosslinked cellulose gum, magnesium stearate) or placebo (the
placebo formulation was a white oval tablet and contained lactose monohydrate, magnesium stearate and cellulose, purchased from Fagron, Barsbuttel, Germany). There was a 4-wk washout period between each treatment. Blood and urine samples were taken before, during and at the end of each study phase. Each participant was independently and randomly assigned into one of two groups, receiving both treatments in one order or another.

During the protocol, volunteers made 6 visits to the research unit at day 0, 14 and 28 of each experimental period for measurement and sample collection. In practice, with 24-hour urine collected at home during the day and night before the visit, overnight-fasted subjects arrived at the research unit between 7-10 am. A fasting blood sample was collected, followed by questionnaires and measurements of weight, height and blood pressure. Subjects received a light meal and the study tablets before leaving the research unit. Subjects were asked to maintain their lifestyle and normal dietary habits from 4 wk before the first visit until the end of the entire study. Compliance was assessed at the end of each 4-wk period by call back questionnaires recording date of missing dose (if any), changes of physical activity and intensity, use of exotic diet or non-routine medications, and the occurrence of any side effects. Subjects were also asked to return the unconsumed tablets at each follow-up visit.

Intervention was randomized independently by a coin toss for each volunteer who received a random 3-digit code. A decode list (participant identification and subject code) was kept by a third person in order to blind the researcher assessing outcomes. The size and shape of study tablets were the same but of different colour, and participants were not aware of the identification of the two types of study tablets. The quercetin-containing tablet was light green and the placebo was off-white. Since quercetin is light yellow, it is not immediately obvious which tablet is the active, and
subjects were not informed which tablets were placebo or active. Analysis of the
tool images and urine samples was also blinded to the researcher using codes held by a
third party.

Sample collection and assay

Blood pressure was measured on the upper left arm in a quiet room at normal room
temperature, with the use of a cuff-less upper arm blood pressure monitor
(Panasonic Co., Japan). Before blood pressure recordings were made, participants
rested for 15 min in a seated position. At each assessment, 3 consecutive blood
pressure readings were recorded at 5 min intervals. The average of these
measurements was used for analysis.

Venous blood was collected following a standard venepuncture protocol into a
sodium fluoride/potassium oxalate blood collection tube (GreinerBioOne, Austria).
Blood samples were immediately centrifuged at 3 000 g, 4 °C for 10 min and aliquots
were stored at -80 °C until analysis. 24-hour urine samples were collected by
volunteers in 3 L sterile urine container (Simport, Canada) which contained 3 g of L-
ascorbic acid (MP Biomedicals, France). The urine samples were weighed before
centrifugation at 2 000 g, 4 °C for 10 min before storage at -20 °C. Urine samples for
uric acid assay were diluted 10-fold before storage at -80 °C.

Analytical methods

Assessment of uric acid in plasma and urine samples was by a specific coupled
enzyme reaction, followed by colorimetric determination at 520 nm. The protocol
was modified for use in a 96-well plate reader (BMGlabtech, Germany) for high-
throughput and improved accuracy. Within-run variation was 1.99±1.20%, and
between-run variation was 2.17±0.52%. Recovery was 92.8±1.6% for plasma and
80.4±3.8% for 10-fold diluted urine. Calibration curves were prepared every time for
each plate, with a slope of 0.550±0.003 per mmol/L uric acid, with $R^2 \geq 0.999$ up to a
maximum concentration of 1.0 mmol/L.

Plasma glucose was measured with a commercial hexokinase-based assay kit for D-
glucose (Sigma-Aldrich, USA). The protocol was modified for use in a 96-well plate
reader. Within-run variation was 4.29±2.21% and between-run variation was
3.33±2.51%. Recovery was 104±8%. Calibration curves were prepared every time
for each plate, with a slope of 0.923±0.006 per g/L D-glucose, with $R^2 \geq 0.999$ up to a
maximum concentration of 1.50 g/L.

Urinary quercetin was quantified by HPLC-ESI/MS as previously described
(26).

**Sample size**

A minimum sample size of 17 was estimated to be required to detect a 10%
difference for the primary efficacy variable, plasma concentration of uric acid, and to
achieve 80% power to meet the two-tailed equality criteria between quercetin and
placebo. A significance level of 0.05 from paired 2-sample $t$ test was set for this two-
sequence, two period cross-over design (38). Coefficient of variation of the blood uric
acid level among the population was ~20% according to previous cohort reports (39; 40; 41)
and 10% of coefficient of variation among study population was estimated since
we pre-screened and selected the upper 50% of the volunteers for plasma uric acid.

**Statistics**

Normality of data distribution was tested by Shapiro-Wilk tests. The paired 2-sample
$t$ test was used for comparison of normally distributed data. Data that were not
normally distributed were compared using the *Wilcoxon signed-rank* test. Relationships between variables were evaluated using Pearson's correlation coefficient. In all cases, a value for $P<0.05$ (2-tailed) was taken to indicate a significant effect. Unless otherwise indicated, results are expressed as mean values and standard deviations (SD). All statistical analyses were performed using the SPSS statistics software (version 21; International Business Machines Corp., New York, USA).
Results

54 male volunteers made contact through advertisements (Figure 1). 52 of them donated blood at the screening stage, with a mean±SD plasma uric acid concentration of 316±56 µmol/L (range 194-472 µmol/L, n=52). 23 subjects were selected and 22 of them completed the study with the following characteristics at baseline: healthy adult males, 29.9±12.9 years, mean BMI of 24.8±3.0 kg/m², blood pressure of normal to (pre-) hypertensive (systolic 122.9±8.1 mm Hg and diastolic 74.3±9.0 mm Hg), fasting blood glucose of normal to impaired fasting glycemia with mean of 5.04±0.56 mmol/L, plasma uric acid of 339±51 µmol/L). No significant change of lifestyle or medication occurred during the study based on the lifestyle maintenance questionnaire, and no adverse events for receiving quercetin or placebo were reported. 24-h urinary excretion of quercetin was 0.810±0.704 µmol during quercetin treatment and 0.200±0.366 µmol during placebo treatment. According to the returned unconsumed tablets, participant self-reports and urinary quercetin, none of the participants was classified as non-compliant.

Plasma uric acid was progressively lowered over time among participants during the quercetin supplementation. From baseline to 2 wk, the mean plasma uric acid showed a downward trend (-15.9 µmol/L, 95% CI, 0.9 to -32.8; P=0.06). From baseline to 4 weeks, the mean plasma uric acid was decreased significantly by -26.5 µmol/L (95% CI, -7.6 to -45.5, P=0.008). Plasma uric acid remained unchanged throughout the placebo period: 95% CI, -8.9 to 30.0; P=0.27 at the 2-week interval and 95% CI, -15.1 to 25.5; P=0.60 after 4-weeks. No difference was observed between the baselines of each arm (P=0.21) (Table 1, Figure 2).
There was a trend for mean diastolic blood pressure to decrease by -2.0 mm Hg (95% CI, 0.1 to -4.1; \( P=0.07 \)) during the quercetin phase, whereas there was no change during the placebo phase. No change was observed in fasting glucose nor in systolic blood pressure in either group by either treatment (Table 1). Renal excretion of uric acid was assessed by total 24-h urinary uric acid and did not significantly vary between the two time points after either treatment: from 2.15±1.80 to 1.61±1.56 mmol after quercetin treatment (\( P=0.11 \), Wilcoxon signed-rank test) and from 1.42±1.33 to 1.64±1.42 mmol after placebo treatment (\( P=0.35 \), Wilcoxon signed-rank test).
In this randomized controlled trial, supplementation with quercetin at 500 mg/d for 4 wk progressively reduced plasma concentrations of uric acid without inducing changes in BMI, in fasting blood glucose or showing any adverse effects. The reduction in plasma uric acid was equivalent to ~8% with high significance (p value of 0.008 after 4 wk). The dose of quercetin was carefully considered based on both realistic food composition and a bioavailability test we which we have previously reported on healthy volunteers. In this comparison, we showed that quercetin (as glycoside conjugates) in 100 g fresh red onion provides a similar amount of bioavailable quercetin to the tablet used here (500 mg of pure quercetin aglycone), as assessed using urinary excretion \(26\). This dose was sufficient to produce the observed change after 4 wk, and provided a more reproducible, practical and acceptable form of consuming quercetin. Similar approaches have been reported recently \(42; 43\).

There are several possible mechanisms for the observed change in plasma uric acid. The most likely is the direct inhibition of xanthine oxidoreductase activity, since, \textit{in vitro}, bovine xanthine oxidoreductase is inhibited strongly by quercetin \((K_i = 1.40\pm0.78 \text{ µmol/L})\) \(44\). The drug, allopurinol, is comparable \((K_i = 0.34\pm0.22 \text{ µmol/L})\) \(45\) and furthermore some conjugates such as quercetin-4'-O-glucuronide also inhibited xanthine oxidoreductase \((K_i =0.25\pm0.03 \text{ µmol/L})\) \(27\). Additional mechanisms are also possible, including promoted renal excretion of uric acid, which could be as a result of an increased glomerular filtration of uric acid. Some drugs such as Losartan inhibit directly URAT1, involved in uric acid reabsorption, and thereby decrease plasma uric acid \(45\), whereas some treatments down regulate mURAT1 and mGLUT9 in mice \(46\). Up-regulation of transporters mOAT1 \(46\), rOAT1 \(47\) and
hOAT1[^48], which increase kidney urate secretion in the proximal tubules of the renal cortex, is also possible. However, a change in urinary excretion is unlikely since 2-week of quercetin administration did not change renal excretion, as assessed using 24 h urine. This implies an overall effect of quercetin on uric acid production rather than an increase in excretion. Other additional mechanisms could involve an indirect antioxidant effect that reduces microvascular ischemia in glomeruli and leads to increased local blood flow, dilation of afferent arterioles, and competition for reabsorption with ions such as sodium and potassium that exert osmotic effects[^49].

A trend for reduction of diastolic blood pressure after quercetin supplementation lends partial support to this hypothesis. The -2.0 mm Hg (95% CI, 0.1 to -4.1; \(P=0.07\)) trend in reduction is potentially noteworthy, since a decrease of similar magnitude has been calculated to result in a substantial decrease in the prevalence of hypertension in population studies[^50-51]. We found no significant effect on systolic blood pressure in this study. Quercetin has been shown to reduce systolic and diastolic blood pressure in hypertensive subjects[^52], but our subjects were chosen for their high blood uric acid levels and not specifically for exhibiting hypertension.

Quercetin has demonstrated some effects on various biomarkers in intervention studies, but the results are dependent on dose, nature of the cohort and length of time of treatment[^42,43,53-55]. Some effects of quercetin may only be seen for defined genotypes[^56]. A very limited number of studies have examined changes in plasma uric acid as a result of quercetin supplementation or high flavonol-diets, but none as a primary outcome. For example, 150 mg per day for 6 weeks gave no change in plasma uric acid[^39], and a diet high in onions and tea for 2 weeks did not change plasma uric acid in patients with type 2 diabetes[^33].
The present study was intentionally designed to be on a homogeneous population with higher than average blood uric acid to minimise confounding influences of gender, medication, diet, or other lifestyle factors. Hence, our result may be valid only for male individuals who are mildly or pre-hyperuricemic but otherwise healthy, and we cannot predict if the findings will extend to populations that include lower plasma uric acid level, females, hypertensive, older or younger populations. The role of habitual diet should also be considered. The intervention in the present study was designed to provide proof of principle and only one dose was tested, but there were no adverse events. Quercetin is part of the normal diet and consumed in very different amounts by individuals according to their dietary patterns.

It is noteworthy in our study that the hypo-uricemic effect of quercetin is more significant in subjects with higher uric acid level (Figure 3), which is in accordance with animal models. These findings have served implications. Dietary quercetin could help to maintain a healthy blood uric acid, and help to prevent formation of uric acid crystals (gouty arthritis). Although hyperuricemia alone is not sufficient to cause gout, a dose-response relationship between serum uric acid and the risk of developing gout is well documented. These findings may also help recovering gout patients where the primary treatment is to achieve an end point of serum uric acid levels less than 360 µmol/L over a period of three months. This includes the use of the drug allopurinol to inhibit xanthine oxidoreductase and uric acid production, or the use of uricosuric drugs which increase renal excretion of uric acid. However, for patients also presenting kidney disease, liver disease, diabetes, congestive heart failure or hypertension, the dosage of allopurinol has to be adjusted in this stage. Once restored, patients are often advised to make comprehensive dietary modifications for prevention against recurrent gout attacks. In the above
situations, adoption of one quercetin tablet that has efficacy to reduce blood uric acid in the habitual diet is easier to adhere to compared to making major dietary changes. Therefore quercetin may be a promising approach to lower uric acid in individuals with above-optimal blood uric acid either for those at high risk who have not yet developed any disease, or for patients recovering after therapy.
Acknowledgements

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Conflict of interest: This work did not receive funding from a commercial organisation, but GW has recently, or currently, received other research funding from Nestle and Florida Department of Citrus, and conducted consultancy for Nutrilite, USA.

The authors’ responsibilities: YS: study concept and design, data interpretation, volunteer recruitment, clinical study management, protocol implementation, sample acquisition, data collection and analysis, statistical analysis, writing and revision of the manuscript; GW: supervision of the study, study concept and design, writing and revision of the manuscript. YS had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. GW had primary responsibility for final content. Both authors have read and approved the final manuscript.
References


### Tables

**Table 1** Effect of quercetin and placebo treatments on plasma biomarkers and blood pressure (n=22) $^a$

<table>
<thead>
<tr>
<th></th>
<th>Quercetin</th>
<th>Placebo</th>
<th>$P$ value</th>
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<td></td>
<td>Measures, mean±SD</td>
<td>Mean difference from baseline (95% CI)</td>
<td>$P$ value</td>
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<tr>
<td></td>
<td>Quercetin Mean difference from baseline (95% CI)</td>
<td>Placebo Mean difference from baseline (95% CI)</td>
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<tr>
<td>Plasma uric acid, µmol/L</td>
<td>Baseline 330±56</td>
<td>315±45 0.21</td>
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<td></td>
<td>2-wk 314±55 -15.9 (0.9, -32.8) 0.06 $^*$</td>
<td>325±52 10.6 (-8.9, 30.0) 0.27</td>
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<tr>
<td></td>
<td>4-wk 304±48 -26.5 (-7.6, -45.5) 0.008 $^{**}$</td>
<td>320±47 5.2 (-15.1, 25.5) 0.60</td>
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</tr>
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<td>Plasma glucose, mmol/L</td>
<td>Baseline 5.04±0.60</td>
<td>5.09±0.49 0.35</td>
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<td></td>
<td>2-wk 5.01±0.65 -0.03 (0.15, -0.21) 0.73</td>
<td>5.13±0.58 0.03 (-0.12, 0.19) 0.65</td>
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<tr>
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<td>4-wk 5.10±0.69 0.06 (-0.13, 0.26) 0.48</td>
<td>5.02±0.77 -0.07 (0.18, -0.33) 0.57</td>
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<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>Baseline 123.2±7.2</td>
<td>122.5±9.9 0.58</td>
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<td>4-wk 122.0±8.9 -1.1 (1.7, -4.0) 0.41</td>
<td>124.6±10.6 2.1 (-0.8, 5.1) 0.14</td>
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<tr>
<td>Diastolic blood pressure, mm Hg $^b$</td>
<td>Baseline 73.8±9.2</td>
<td>73.1±7.8 0.43</td>
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<td>4-wk 71.8±8.9 -2.0 (0.1, -4.1) 0.07 $^*$</td>
<td>72.7±9.7 -0.4 (2.0, -2.9) 0.79</td>
<td></td>
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</tbody>
</table>

$^*$ indicates $P<0.1$ and $^{**}$ indicates $P<0.05$ when compared to baseline.

$^a$ 2-tailed paired $t$ test were used if not stated otherwise.

$^b$ Wilcoxon signed-rank test was used as the data is not normally distributed.
Figure legends

**Figure 1** Participant flow diagram of the progress through this double-blinded, placebo-controlled, randomized, cross-over trial

**Figure 2** Effect of consumption of quercetin on plasma uric acid

Comparison of plasma uric acid at baseline, 2 and 4 wk after consuming quercetin (containing 500 mg of quercetin) or a placebo daily in 22 healthy subjects. Error bars indicate 95% CI. * indicates a trend \((P<0.1)\) and ** indicates significance \((P<0.05)\) when compared to baseline by paired \(t\) test.

**Figure 3** Changes of plasma uric acid from observations in relation to baseline plasma uric

The magnitude of plasma uric acid reduction was higher in individuals with higher baseline plasma uric acid in both treatments. Plasma uric acid in the majority of subjects declined after 4 wk in treatment by quercetin (17/22) but not by placebo (10/22). Correlation coefficient \(r\) was calculated by the *Pearson* test.
Figures

54 Assessed for eligibility
52 Screened for plasma uric acid concentration

31 Excluded
23 Not meeting inclusion criteria
6 Declined to participate
2 Other reasons

23 Randomized

QUERCETIN

14 Randomized to receive quercetin first
13 Completed all follow-up in quercetin phase
1 Discontinued intervention (subject withdrawn)

PLACEBO

9 Randomized to receive placebo first
9 Completed all follow-up in placebo phase
0 Discontinued intervention

4-week washout Followed by crossover

9 Received quercetin
9 Completed all follow-up in quercetin phase

13 Received placebo
13 Completed all follow-up in placebo phase

22 included in analysis

Figure 1
Figure 2
Figure 3