



Effects of Pentoxifylline on Soluble Klotho Concentrations and Renal Tubular Cell Expression in Diabetic Kidney Disease

Diabetes Care 2018;41:1817–1820 | <https://doi.org/10.2337/dc18-0078>

Juan F. Navarro-González,^{1,2,3}
María Dolores Sánchez-Niño,^{3,4}
Javier Donate-Correa,^{1,3}
Ernesto Martín-Núñez,¹ Carla Ferri,¹
Nayra Pérez-Delgado,⁵ José Luis Górriz,^{3,6}
Alberto Martínez-Castelao,^{3,7}
Alberto Ortiz,^{3,4} and
Carmen Mora-Fernández¹

OBJECTIVE

The effect of pentoxifylline on Klotho levels in patients with type 2 diabetes mellitus with chronic kidney disease (CKD) was assessed in a post hoc analysis of the Pentoxifylline for Renoprotection in Diabetic Nephropathy (PREDIAN) trial.

RESEARCH DESIGN AND METHODS

Circulating and urinary tumor necrosis factor- α (TNF- α) and Klotho were measured before and after 1 year of pentoxifylline. The effect on Klotho expression was assessed in cultured renal tubular cells.

RESULTS

Pentoxifylline administration resulted in decreased serum and urinary TNF- α , whereas serum and urinary Klotho increased significantly. Changes in urinary Klotho, urinary TNF- α , and phosphorus were associated with changes in serum Klotho; changes in estimated glomerular filtration rate, urinary TNF- α , and albuminuria were related to urinary Klotho variation. In renal tubular cells, pentoxifylline prevented the decrease in Klotho expression induced by inflammatory cytokines or albumin.

CONCLUSIONS

Pentoxifylline increased Klotho levels in patients with diabetes with stage 3–4 CKD and prevented reduced Klotho expression in vitro. This beneficial effect may be related to anti-inflammatory and antialbuminuric activity.

Klotho is a transmembrane protein predominantly expressed in kidney tubular cells with a soluble form that functions as a humoral factor, with beneficial biological effects including antiaging and nephroprotective functions, as observed by its role in diabetic kidney disease (DKD) (1–6). Renal Klotho expression is markedly diminished in DKD (2), whereas serum Klotho decreases in patients with type 2 diabetes mellitus (T2DM) as nephropathy progresses (3).

The Pentoxifylline for Renoprotection in Diabetic Nephropathy (PREDIAN) trial (7) showed that pentoxifylline administration in patients with T2DM with stage 3–4 chronic kidney disease (CKD) results in a slower decrease in estimated glomerular filtration rate (eGFR) and a greater reduction of albuminuria. In this post hoc analysis, we investigated the effects of pentoxifylline on soluble Klotho levels. In addition, pentoxifylline regulation of Klotho expression was explored in proximal tubule epithelial cells exposed to albumin and inflammatory injury.

¹Unidad de Investigación, Hospital Universitario Nuestra Señora de Candelaria, Santa Cruz de Tenerife, Spain

²Servicio de Nefrología, Hospital Universitario Nuestra Señora de Candelaria, Santa Cruz de Tenerife, Spain

³GEENDIAB (Grupo Español para el Estudio de la Nefropatía Diabética) y REDINREN (Red de Investigación Renal), Madrid, Spain

⁴Instituto de Investigación Sanitaria-Fundación Jiménez Díaz-Universidad Autónoma de Madrid y Fundación Renal Iñigo Álvarez de Toledo-Instituto Reina Sofía de Investigación Nefrológica, Madrid, Spain

⁵Servicio de Análisis Clínico, Hospital Universitario Nuestra Señora de Candelaria, Santa Cruz de Tenerife, Spain

⁶Hospital Clínico Universitario de Valencia, INCLIVA, Universitat de Valencia, Valencia, Spain

⁷Hospital Universitario de Bellvitge, IDIBELL, Barcelona, Spain

Corresponding author: Juan F. Navarro-González, jnavgon@gobiernodecanarias.org.

Received 11 January 2018 and accepted 4 May 2018.

© 2018 by the American Diabetes Association. Readers may use this article as long as the work is properly cited, the use is educational and not for profit, and the work is not altered. More information is available at <http://www.diabetesjournals.org/content/license>.

RESEARCH DESIGN AND METHODS

Details of the PREDIAN trial have been previously published (7). Participants were randomly assigned to a pentoxifylline or control group, and the current results are after 1-year of follow-up. Tumor necrosis factor- α (TNF- α) was measured by immunoenzymatic ELISA and soluble Klotho by a solid phase sandwich ELISA (Immuno-Biological Laboratories, Takasaki, Japan). Urinary Klotho and TNF- α were normalized to urinary creatinine concentrations. All measurements were performed while blinded to participant characteristics and group assignment.

Mouse cortical tubule cells were cultured with the addition of 10 mg/mL BSA, 100 ng/mL recombinant human-soluble TNF-like weak inducer of apoptosis (TWEAK), or 30 ng/mL murine TNF- α after prior dose-response studies (8). Pentoxifylline was added 1 h before stimulation. Western blot used rabbit polyclonal anti-Klotho (1:500; Calbiochem, La Jolla, CA) as the primary antibody. One microgram RNA was reverse-transcribed, and real-time PCR was performed using the $2^{-\Delta\Delta C_t}$ method. Expression levels are expressed as ratios to GAPDH.

RESULTS

Of the 169 patients in the PREDIAN trial, 166 (85 control group, 81 pentoxifylline group) who completed 1-year follow-up were included in this analysis. Baseline eGFR was 37.4 ± 12.1 mL/min/1.73 m², and albuminuria 1,100 mg/day (640–1,800 mg/day); 68.3% of patients had stage 3 CKD. Serum and urinary Klotho were 295.9 pg/mL (223.4–406.5 pg/mL) and 54.1 ng/g (41.2–70.5 ng/g), respectively, and serum and urinary TNF- α were 15.2 pg/mL (11.9–17.4 pg/mL) and 16.1 ng/g (10.0–20.1 ng/g), respectively. Serum and urinary Klotho were higher in stage 3 than in stage 4 CKD (302.9 pg/mL [240–429.5 pg/mL] and 60.0 ng/g [44.9–88.7 ng/g] vs. 282.6 pg/mL [210.2–371.2 pg/mL] and 41.4 ng/g [30.1–52.2 ng/g]; $P = 0.13$ and < 0.001 , respectively). Correlation analysis showed that serum Klotho was negatively associated with phosphorus ($r = -0.21$; $P < 0.01$), whereas urinary Klotho was directly related to eGFR ($r = 0.59$; $P < 0.01$) and inversely correlated with diabetes duration ($r = -0.17$; $P < 0.05$) and serum phosphorus ($r = -0.35$; $P < 0.01$). No correlation was observed between serum and urinary Klotho or between serum and urinary TNF- α .

After 1 year, the control group showed a mean reduction of 9.0% in eGFR ($P < 0.01$) and a 4.4% increase in albuminuria ($P < 0.01$), whereas in patients receiving pentoxifylline, eGFR decreased by 3.9% ($P < 0.01$) and albuminuria by 12.5% ($P < 0.001$) ($P < 0.01$ and < 0.001 between groups, respectively). Serum and urinary TNF- α did not change in the control group, but urinary TNF- α significantly decreased in the pentoxifylline group (Fig. 1A). Serum Klotho increased in patients receiving pentoxifylline (mean increment 5.9% vs. baseline [95% CI 2.4–9.4%]; $P < 0.05$), with a mean difference of 27.5 pg/mL between groups (95% CI 22–31.1 pg/mL; $P < 0.01$). Urinary Klotho decreased by 3.9% (–5.1 to –2.7%; $P < 0.01$) in the control group, whereas it increased by 9.3% (4.6–13.9%; $P < 0.001$) in the pentoxifylline group (mean difference 7.7 ng/g [5.9–9.4 ng/g]; $P < 0.001$ between groups) (Fig. 1B). Changes in urinary Klotho, urinary TNF- α , and phosphorus were independently associated with variations in serum Klotho (adjusted $R^2 = 0.44$; $P < 0.001$), whereas changes in eGFR, albuminuria, and urinary TNF- α were independently associated with urinary Klotho variations (adjusted $R^2 = 0.60$; $P < 0.0001$).

The effects of pentoxifylline on Klotho expression were analyzed in renal tubular cells. After exposure to albumin to mimic DKD, Klotho expression significantly decreased, which was abrogated by pentoxifylline. Pretreatment with pentoxifylline resulted in a dose-dependent increased expression of Klotho protein and mRNA (Fig. 1C and D). To mimic the inflammatory milieu of injured kidneys, tubular cells were exposed to TNF- α and TWEAK, cytokines with a proven ability to downregulate Klotho expression (8). Decreased Klotho expression induced by these cytokines was completely prevented by pentoxifylline (Fig. 1E and F).

CONCLUSIONS

This study shows that in patients with T2DM with stage 3–4 CKD, treatment with pentoxifylline leads to a significant increase in serum and urinary Klotho concentrations, with clinical findings supported by experimental data showing that pentoxifylline is able to prevent the downregulation of Klotho protein and mRNA expression induced by albumin, TNF- α , and TWEAK in renal tubular cells. The soluble form of Klotho functions as a humoral factor that regulates various signaling pathways with beneficial biological effects. The kidney is

the main source of soluble Klotho (9), and Klotho production is severely reduced in human CKD (10). An early decrease in renal Klotho expression has been reported as a characteristic finding of DKD (2). In the current study, urinary Klotho levels were higher in participants with stage 3 CKD than in more advanced CKD and showed a direct correlation with eGFR. However, no association was found between serum and urinary Klotho, indicating that urinary Klotho is not the result of glomerular filtration. This finding is in accordance with studies that reported that soluble Klotho is not filtered across the glomerular barrier and that urinary Klotho is tubular in origin (11).

Only two previous clinical studies in patients with T2DM have analyzed the effect of therapies on soluble Klotho, specifically the effect of renin-angiotensin system blockade. Karalliedde et al. (12) reported that valsartan increased serum Klotho by 73.7%, whereas Lim et al. (13) observed that losartan enhanced circulating Klotho by 23%. In the current study, serum and urinary Klotho increased significantly by 5.9 and 9.3%, respectively. Of note, participants in previous studies had a preserved renal function (mean eGFR 92.3 mL/min/1.73 m²), whereas eGFR in the current study was 37.4 ± 12.1 mL/min/1.73 m², reflecting an important reduction in renal functional mass, which can explain the lower percent increases of soluble Klotho. Finally, the current clinical study is the first to our knowledge of a therapeutic intervention on urinary Klotho.

Although the intimate mechanisms need additional investigation, pentoxifylline may positively regulate Klotho on the basis of its anti-inflammatory properties. Patients receiving pentoxifylline exhibited a decrease in serum and urinary TNF- α without correlation between these parameters, indicating that TNF- α is produced within the kidneys. Of note, changes in urinary TNF- α were negatively and independently associated with the variation in serum and urinary Klotho concentrations. Furthermore, our in vitro experiments showed that pentoxifylline prevented the TWEAK and TNF- α -induced Klotho downregulation; the reduction of urinary albumin excretion in pentoxifylline-treated patients could contribute to this effect because albuminuria causes tubular inflammation and renal injury (14) and directly reduces Klotho levels in tubular cells in vivo and in culture (15), as confirmed in the current study.

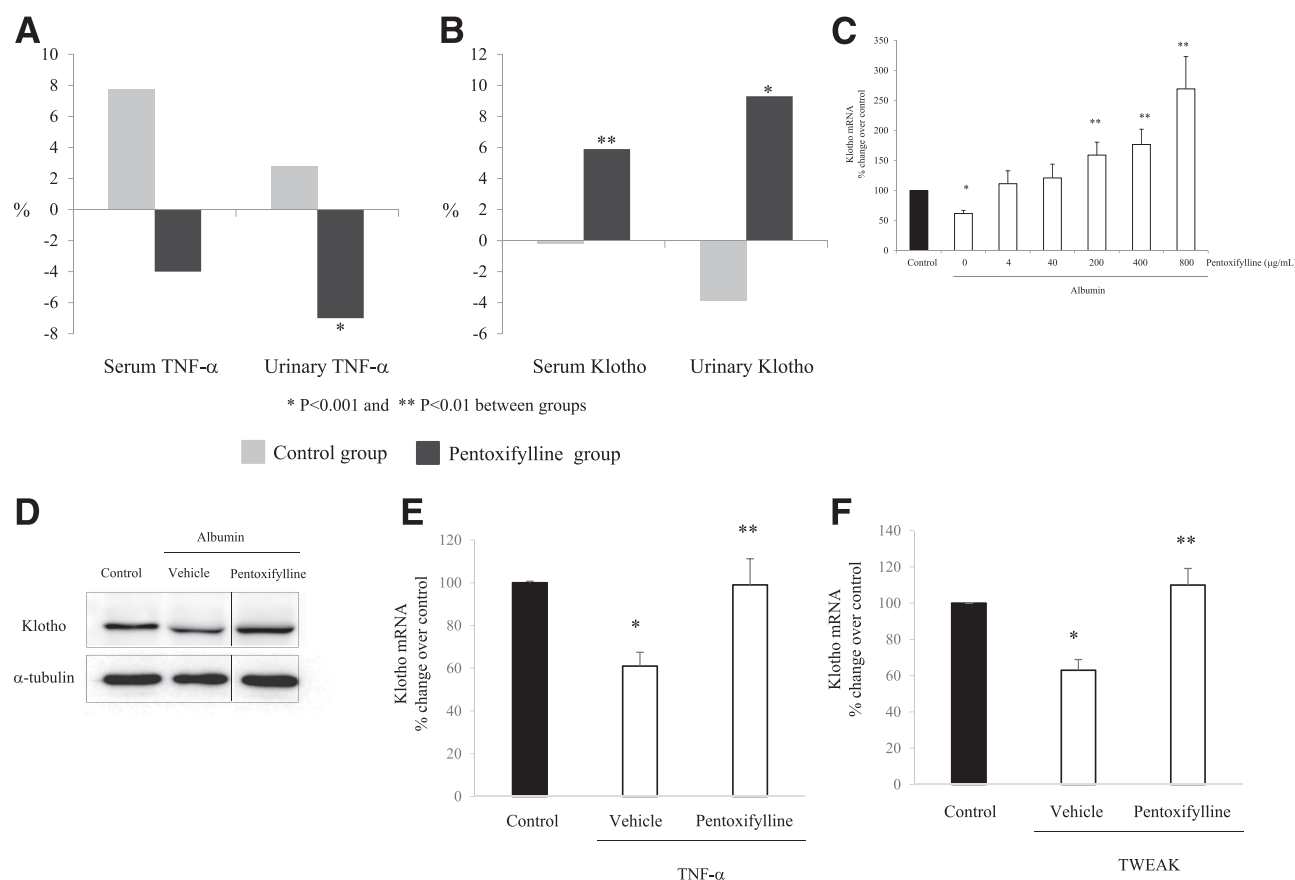


Figure 1—Clinical and in vitro effects of pentoxifylline. **A** and **B**: Mean percent changes of TNF-α and soluble Klotho with respect to baseline according to study group. **C–F**: Pentoxifylline prevents the decrease in Klotho expression in response to albumin and to the inflammatory cytokines TWEAK and TNF-α in vitro. **C**: Kidney tubular cells were stimulated with various concentrations of pentoxifylline for 1 h and then with 10 mg/mL albumin for 3 h. Klotho mRNA expression level was decreased after albumin stimulation alone but increased in cells pretreated with pentoxifylline. * $P < 0.002$ vs. control; ** $P < 0.01$ vs. albumin alone. **D**: Cells were stimulated with 40 μg/mL pentoxifylline for 1 h and then with 10 mg/mL albumin for 3 h. Protein from whole-cell lysates was studied. A representative Western blot is shown. Noncontiguous lanes of the same gel have been spliced together. All the lanes were run on the same gel at the same time. This alteration is indicated in the figure by a dividing line between the lanes. The estimated size of the Klotho band is 131 kDa. **E** and **F**: Kidney tubular cells were stimulated with 40 μg/mL pentoxifylline for 1 h and with cytokines (30 ng/mL TNF-α and 100 ng/mL TWEAK) for 3 or 6 h. Inflammatory cytokines decrease Klotho mRNA levels, and this was prevented by pentoxifylline pretreatment. * $P < 0.005$ vs. control; ** $P < 0.05$ vs. cytokine alone.

In conclusion, pentoxifylline administration to patients with T2DM with stage 3–4 CKD increased serum and urinary Klotho levels, which may be related to anti-inflammatory and antialbuminuric effects. Given the nephroprotective and antiaging effects of Klotho, further characterization of the Klotho-preserving effect of pentoxifylline may contribute to the design of novel therapeutic strategies aimed at preserving Klotho expression to improve kidney and survival outcomes in CKD.

Acknowledgments. The authors thank the study participants of the PREDIAN trial.

Funding. The PREDIAN trial was funded by the Instituto de Salud Carlos III (ISCIII) (Ref. EC07/90021) (Spanish Ministry of Economy, Industry and Competitiveness). This work was supported by Fondo de Investigación en Salud PI15/00298, CP14/00133, PI16/02057, PI16/00024, ISCIII-Redes

Temáticas de Investigación Cooperativa en Salud (RETIC)-REDINREN RD16/0009, Sociedad Española de Nefrología, and Asociación Científica para la Investigación Nefrológica. The authors acknowledge cofunding by Fondo Europeo de Desarrollo Regional, Unión Europea ("Una forma de hacer Europa"). M.D.S.-N. is recipient of a Miguel Servet Research Contract. J.D.-C. is recipient of a Sara Borrell Contract (CD16/00165). E.M.-N. is recipient of a research contract from the ISCIII (FI14/00033). C.F. is recipient of a research contract from the ISCIII-RETIC-REDINREN (RD16/0009/0022). The funders played no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Duality of Interest. No potential conflicts of interest relevant to this article were reported.

Author Contributions. J.F.N.-G., M.D.S.-N., J.D.-C., E.M.-N., C.F., N.P.-D., J.L.G., A.M.-C., A.O., and C.M.-F. approved the final version of the manuscript for publication. J.F.N.-G., J.L.G., A.M.-C., A.O., and C.M.-F. analyzed and interpreted the data. J.F.N.-G., A.O., and C.M.-F. equally contributed to the study concept and design. J.F.N.-G. and C.M.-F. performed the statistical

analysis and wrote the manuscript. M.D.S.-N. and A.O. carried out the in vitro experiments. J.D.-C., E.M.-N., C.F., and N.P.-D. processed the serum and urine samples and performed ELISA measurements. J.L.G., A.M.-C., and A.O. reviewed the manuscript. J.F.N.-G. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

References

- Golembiewska E, Stępniewska J, Kabat-Koperska J, Kędzierska K, Domański M, Ciechanowski K. The role of Klotho protein in chronic kidney disease: studies in animals and humans. *Curr Protein Pept Sci* 2016;17:821–826
- Asai O, Nakatani K, Tanaka T, et al. Decreased renal α-Klotho expression in early diabetic nephropathy in humans and mice and its possible role in urinary calcium excretion. *Kidney Int* 2012;81:539–547
- Wu C, Wang Q, Lv C, et al. The changes of serum sKlotho and NGAL levels and their correlation in type 2 diabetes mellitus patients with different stages of urinary albumin. *Diabetes Res Clin Pract* 2014;106:343–350

4. Lin Y, Kuro-o M, Sun Z. Genetic deficiency of anti-aging gene Klotho exacerbates early nephropathy in STZ-induced diabetes in male mice. *Endocrinology* 2013;154:3855–3863
5. Kang WL, Xu GS. Atrasentan increased the expression of Klotho by mediating miR-199b-5p and prevented renal tubular injury in diabetic nephropathy. *Sci Rep* 2016;6:19979
6. Liu YN, Zhou J, Li T, et al. Sulodexide protects renal tubular epithelial cells from oxidative stress-induced injury via upregulating Klotho expression at an early stage of diabetic kidney disease. *J Diabetes Res* 2017;2017:4989847
7. Navarro-González JF, Mora-Fernández C, Muros de Fuentes M, et al. Effect of pentoxifylline on renal function and urinary albumin excretion in patients with diabetic kidney disease: the PRE-DIAN trial. *J Am Soc Nephrol* 2015;26:220–229
8. Moreno JA, Izquierdo MC, Sanchez-Niño MD, et al. The inflammatory cytokines TWEAK and TNF α reduce renal Klotho expression through NF κ B. *J Am Soc Nephrol* 2011;22:1315–1325
9. Lindberg K, Amin R, Moe OW, et al. The kidney is the principal organ mediating Klotho effects. *J Am Soc Nephrol* 2014;25:2169–2175
10. Koh N, Fujimori T, Nishiguchi S, et al. Severely reduced production of Klotho in human chronic renal failure kidney. *Biochem Biophys Res Commun* 2001;280:1015–1020
11. Hu MC, Shi M, Zhang J, et al. Renal production, uptake and handling of circulating α Klotho. *J Am Soc Nephrol* 2016;27:79–90
12. Karalliedde J, Maltese G, Hill B, Viberti G, Gnudi L. Effect of renin-angiotensin system blockade on soluble Klotho in patients with type 2 diabetes, systolic hypertension, and albuminuria. *Clin J Am Soc Nephrol* 2013;8:1899–1905
13. Lim SC, Liu JJ, Subramaniam T, Sum CF. Elevated circulating alpha-Klotho by angiotensin II receptor blocker losartan is associated with reduction of albuminuria in type 2 diabetic patients. *J Renin Angiotensin Aldosterone Syst* 2014;15:487–490
14. Jheng HF, Tsai PJ, Chuang YL, et al. Albumin stimulates renal tubular inflammation through an HSP70-TLR4 axis in mice with early diabetic nephropathy. *Dis Model Mech* 2015;8:1311–1321
15. Fernández-Fernández B, Izquierdo MC, Valiño-Rivas L, et al. Albumin downregulates Klotho in tubular cells. *Nephrol Dial Transplant*. 7 February 2018 [Epub ahead of print]. DOI: 10.1093/ndt/gfx376