Retraction

Retracted: Evolution of China's Interprovincial Water Flow Network

Discrete Dynamics in Nature and Society

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] T. Huang, Y. Li, and Q. Zhang, "Evolution of China's Interprovincial Water Flow Network," *Discrete Dynamics in Nature and Society*, vol. 2021, Article ID 2235266, 6 pages, 2021.

Research Article
Evolution of China's Interprovincial Water Flow Network

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Traditionally, water governance focuses on water only. The emergence of virtual water breaks this limitation and integrates economic and social systems with the water resource system. This paper establishes an interprovincial complex network of virtual water flows in China, based on the theory on complex network, which has rarely been adopted to study the virtual water transfer network. Then, the authors analyzed the pattern and evolutionary features of China's interprovincial virtual water flow network. In this way, the complex network theory was successfully applied to explore the virtual water flows across provinces in China.

1. Introduction

1.1. Virtual Water Flow. The emerging concept of virtual water expands the scope of the water-centered traditional water governance model and integrates economic and social systems with the water resource system. Virtual water refers to the amount of water resources required to offer products or services, which flows along regional trade [1]. On the national scale, Schwarz et al. [2] studied the relationship between the agricultural trade and virtual water flow in Peru and proved that the economic water efficiency of the export of agricultural products is much more economical than that of the import of agricultural products, thereby reducing the utilization of local water resources. Muratoglu [3] calculated the virtual water flow in domestic and foreign wheat trade of Turkey in 2008–2019 and discovered that the worldwide wheat export promotes the saving of global virtual water. Through the research on the international trade of avocado, Caro et al. [4] learned that the virtual water resources involved in the trade flow from water-deficient countries like Mexico to water-rich countries like the United States; this virtual water flow further damages the environment of poor countries. Bazrafshan et al. [5] calculated the water footprint and virtual water trade of date palm planting in Iran of 2008–2016 and put forward the suggestions on improving water resources. Taking Iran as an example, Delpasand et al. [6] demonstrated that economic income can be improved through proper management of water trade in the case of water shortage. Selim and Abdalbaki [7] constructed the social network of virtual water trade between the countries in the Nile River Basin of 2000–2013, found that these countries have a stable and balanced structure of crop output, and determined Kenya, Uganda, and Tanzania as the most influential and effective exporters of agricultural products. Chini and Stillwell [8] established a resource accounting model to couple the embedded water resources with the international power trade of the entire Europe on the time scale, examined the data of the operator network in the European power transmission system, and drew two conclusions: the trading volume of virtual water increased in 2002–2015 and was significantly affected by season and power policy.

1.2. Complex Network Application. In international energy trade, the theory of complex network has been widely used to study the pattern and evolution features of energy trade networks for oil and gas [9–14]. In recent years, this theory

has also been applied to examine the pattern and evolution features of the network composed of implicit rare earth and energy in trade. Wang et al. [15] combined input-output analysis and complex network theory, constructed the transfer network of implicit rare earth across industries in China, and presented the following conclusions: the clustering coefficient and mean path length show the small world property in the network; chemicals and waste sectors have the strongest direct, indirect, and intermediate effects, and the 41 sectors identified by the community test can be divided into 4 clusters. Chen et al. [16] implemented various tools of complex network analysis and disclosed the structure of implicit energy flow network on global, regional, and country levels. Konar et al. [17] investigated the virtual water trade of global food in 2000 and found the key role of the US in maintaining the global network structure. Dalin et al. [18] studied the evolution of virtual water flow network in the food trade between countries in 1986–2007 and noticed the marked increase in virtual water import of agricultural products in China after 2000. Through network analysis, Fang and Chen [19] examined the virtual water trade networks between the regions in Heihe River Basin from 2002 to 2010 and revealed that these networks tend to be symbiotic or interdependent. Tuninetti et al. [20] presented a virtual water flow network prediction model for agricultural products, pointing out that population, geographical distance, and agricultural efficiency are the main promoters of bilateral trade. Using the multiregional input-output model, Deng et al. [21] computed the virtual water trade between 19 major countries (G20 excluding European Union member states) in 2006–2015 and researched the virtual water trade network through network analysis. Garcia and Mejia [22], Konar et al. [23], and Chini et al. [24] have also carried out similar studies.

2. Evolution Model of China's Provincial Virtual Water Flow Network

2.1. Water-Extended Multiregional Input-Output Model. The input-output (IO) analysis is an economic analysis approach proposed by Leontief. By preparing input-output tables, the IO analysis establishes the corresponding input-output model to analyze the dependence between the sectors of national economy in various production links. The multiregional input-output (MRIO) analysis can consider the production and consumption differences between regions in terms of technology, volume, and structure, making up for the defects of the single-region input-output model. The basic form of MRIO table consists of m regions, n sectors, and the following information:

(1) z_{ij}^{rs} is the intermediate input of sector i of region r to sector j of region s $(r, s = 1, 2, \ldots, m; i, j = 1, 2, \ldots, n)$

(2) y_i^{rs} is the demand of region s (consumer) for the products manufactured by sector i in region r (producer)

(3) v_j^s is the added value of sector j in region s

(4) x_i^r is the total output of sector i in region r

The above parameters adopt monetary unit because the input-output table is usually based on the quantity of value.

According to the row balance model of the input-output table, the total output of sector i in region r can be calculated by

$$x_i^r = \sum_s \sum_j z_{ij}^{rs} + \sum_s y_i^{rs}. \tag{1}$$

The MRIO model can be described as a matrix as follows:

$$X = \mathbf{A}X + \sum_s Y^s. \tag{2}$$

Solving the output vector X,

$$X = (1 - \mathbf{A})^{-1} \times \left(\sum_s Y^s \right) = \mathbf{L} \times \left(\sum_s Y^s \right), \tag{3}$$

where $\mathbf{A}$ is the direct consumption coefficient matrix and $\mathbf{L} = (1 - \mathbf{A})^{-1}$ is the Leontief inverse matrix of the MRIO model, which indicates the domestic output required to satisfy a unit of final demand.

The environmentally extended input-output (EEIO) analysis couples the environmental impact module with the basic IO module to track the direct and indirect environmental impacts of human economic activities via industry associations. The EEIO analysis reflects the environmental impact footprint on individual and regional levels. After carbon emissions row vector is added to the value-type MRIO, the technical coefficient of environmental impacts can be characterized by the direct water consumption (d_i^r) per unit of total output.

According to the row balance relationship in MRIO, the total amount of China's virtual water induced by the domestic final demand in region s can be expressed as follows:

$$vw_{Y^s} = D'\mathbf{L}Y^s = \begin{bmatrix} D^1 \\ D^2 \\ \vdots \\ D^m \end{bmatrix}^T \times \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \cdots & \mathbf{L}^{1m} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \cdots & \mathbf{L}^{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{L}^{m1} & \mathbf{L}^{m2} & \cdots & \mathbf{L}^{mm} \end{bmatrix} \times \begin{bmatrix} Y^{1s} \\ Y^{2s} \\ \vdots \\ Y^{ms} \end{bmatrix}$$

$$= \sum_r \left(D^{1'}\mathbf{L}^{1r} + D^{2'}\mathbf{L}^{2r} + \cdots + D^{m'}\mathbf{L}^{mr} \right) \times Y^{rs}, \tag{4}$$

where $D^r = (d_i^r)_{n \times 1} = (w_i^r / x_i^r)_{n \times 1}$ is the vector of direct water use intensity in region r and w_i^r is the amount of direct water use in sector i and region r.

Formula (4) describes the virtual water implied in the trade of region s. Then, the virtual water implied in the export trade from region r to region s can be described as follows:

$$vw_{Y^{rs}} = \left(D^{1'}\mathbf{L}^{1r} + D^{2'}\mathbf{L}^{2r} + \cdots + D^{m'}\mathbf{L}^{mr} \right) \times Y^{rs}. \tag{5}$$

Formula (5) depicts the amount of virtual water implied in the goods exported from region r to region s, which

includes the direct virtual water ($D^{r\prime}\mathbf{L}^{rr}Y^{rs}$) produced in region r from the trade from region r to region s and the indirect virtual water ($D^{t\prime}\mathbf{L}^{tr}Y^{rs}\,[t \neq r]$) from other regions. Similarly, the virtual water produced in region r is driven by the export trade from other regions to region s because the export trade from region r to other regions involves the input of intermediate products. Therefore, the total amount of virtual water in region r driven by the final demand of region s can be described as follows:

$$vw_{Y^s}^r = \sum_t D^{r\prime}\mathbf{L}^{rt}Y^{ts}, \tag{6}$$

where $vw_{Y^s}^r$ is the pulling effect of the final demand of regions to all regions on the water consumption of region r via the industry chain. In this paper, this effect is defined as the virtual water flow from region r to region s.

According to the symmetry, the total volume of virtual water in region s driven by the final demand of region r can be calculated by the following:

$$vw_{Y^r}^s = \sum_t D^{s\prime}\mathbf{L}^{st}Y^{tr}. \tag{7}$$

Similarly, $vw_{Y^r}^s$ was defined as the virtual water flow from region s to region r.

2.2. Complex Network Model for China's Interprovincial Virtual Water Flow.

Each node in the complex network stands for an economy that outputs or receives virtual water low. The virtual water flows between nodes were defined as edges. The edge weight equals the virtual water volume implied in trade. Therefore, China's interprovincial virtual water flow can be described as a directed weighted network:

$$G = (M, F), \tag{8}$$

where G is China's virtual water flow network; M is the node set of 30 provinces in China; and $F = \{f^{rs}\} = \{\Delta e^{rs} * \alpha^{rs}\}$ where $\alpha^{rs} = \begin{cases} 1, & \text{if } \Delta e^{rs} > 0, \\ 0, & \text{otherwise} \end{cases}$ is the set of virtual water flows between the 30 provinces.

2.2.1. Degree and Weighted Degree.

In China's virtual water flow network, the degree of an economy refers to the number of other economies connected to the economy, reflecting the degree of participation of the economy in the network. Intuitively, an economy with a high degree has a large influence in the network. For a directed network, there are two degrees, namely, input degree (k_{in}^r) and output degree (k_{out}^r):

$$\begin{aligned} k^r &= k_{in}^r + k_{out}^r, \\ k_{in}^r &= \sum_{t(t \neq r)} e^{tr}, \\ k_{out}^r &= \sum_{t(t \neq r)} e^{rt}. \end{aligned} \tag{9}$$

The mean degree is the mean value of all node degrees in the network: $\bar{k} = (1/m)\sum_r (k_{in}^r + k_{out}^r)$.

For weighted China's virtual water flow network, the carbon flow chain between any two economies was no longer treated as binary interactions but weighted by the size of the virtual water flow. Similar to input and output degrees, the weighted input degree (s_{in}^r) and weighted output degree (s_{out}^r) can be obtained as follows:

$$\begin{aligned} s^r &= s_{in}^r + s_{out}^r, \\ s_{in}^r &= \sum_{t(t \neq r)} e^{tr}, \\ s_{out}^r &= \sum_{t(t \neq r)} e^{rt}. \end{aligned} \tag{10}$$

The mean weighted degree is the mean value of all weighted node degrees in the network $\bar{s} = (1/m)\sum_r (s_{in}^r + s_{out}^r)$, which measures the activity of the entire network.

2.2.2. Community Test.

In a complex network, each set of closely correlated nodes can be viewed as a community. The intracommunity correlations are denser than intercommunity correlations. The community test provides a technique to measure the network clustering. The modularity can be calculated by

$$Q = \frac{1}{2f} \times \sum_{r,s} \left(f^{rs} - \frac{s_{out}^r s_{out}^s}{2f} \right) \times \delta(c^r, c^s), \tag{11}$$

where f^{rs} is the flow on the weighted edge from node r to node s; c^r is the community label of node r; and $f = \sum_{r,s} f^{rs}$ is the total flow on weighted edges in the network. If $c^r = c^s$, then $\delta(c^r, c^s) = 1$; otherwise, $\delta(c^r, c^s) = 0$.

3. Measurement and Analysis of China's Provincial Virtual Water Flows

3.1. Measurement and Feature Analysis of Virtual Water in Interprovincial Trade of China.

In terms of virtual water flow sectors, the interprovincial virtual water in China mainly originates from the final demand for the products in the following sectors: agriculture, forestry, animal husbandry, and fishery (AFAF), food manufacturing and processing (FMP), construction, and service industry. In 2012, the final demand of AFAF products created 71.21 billion m^3 of virtual water, about 27.6% of the total virtual water in that year; in 2015, the final demand of construction products created 59.12 billion m^3 of virtual water, about 26.3% of the total virtual water in that year. Dynamically speaking, the proportion of AFAF increased from 23.5% in 2002 to 27.6% in 2012 and nosedived to 17.6% in 2015. The proportion of construction increased from 15.1% in 2007 to 17.6% in 2012 and surged up to 26.3% in 2015. The proportion of FMP declined continuously in 2002–2015 from 21.85 to 18.3%. The total amount of virtual water has experienced the change trend of "first rising and then falling," which is caused by a variety of factors. Among them, the final consumption is the main factor for the growth of virtual water. With the improvement of production technology, the water intensity in

the process of product production is reduced and the production structure is more optimized, resulting in the decrease in virtual water transfer.

Due to the difference in water resource endowment, water resources are of different values in different regions. The water-deficient regions suffer a greater pressure on water resources than water-rich regions if they export the same volume of virtual water. Considering the transfer of virtual water and the abundance of local water, this paper measures the water resource pressure transfer by the ratio of virtual water transfer to water resource volume and views the transfer direction of water resource pressure as the opposite to that of virtual water. According to the pattern of water resource transfer in South and North China in 2015, the two regions have a significant difference in water resource pressure transfer. On the transfer-out/in of water resource pressure, North China transferred out 0.11 and transferred in 0.24 water resource pressure, driven by the trade-induced virtual water transfer; that is, this region had a net transfer-in of 0.13. South China transferred out 0.18 and transferred in 0.05 water resource pressure, driven by the trade-induced virtual water transfer; that is, this region had a net transfer-out of 0.13. On the pressure transfer flows, North China transferred 0.02 water resource pressure to South China, while the latter transferred 0.15 to the former, more than 7 times that of 0.02. Hence, the virtual water transfer implied in interprovincial trade causes a sizeable water resource pressure from South China to North China, which further deteriorates the water shortage in the northern region.

3.2. Intracommunity and Intercommunity Virtual Water Flow Analysis. Based on Gephi 0.9.2, the weighted degrees of the nodes and the mean weighted degree in China's interprovincial virtual water flow network were calculated by formulas (2)–(9) and (2)–(10) for 2002, 2007, 2012, and 2015, respectively. The results show that the mean weighted degree in the network first increased and then declined. Overall, China's interprovincial virtual water flow network exhibited a multipolar trend. Three centers could be observed in the network, namely, North China, East China, and South China.

To analyze the intracommunity and intercommunity virtual water flows in the said network, different communities were marked in different colors: Communities C1–C3 were presented in red, green, and magenta, respectively. The outmost ring was divided into three arcs, each of which represents the composition of the total virtual water volume in a community (percentage), i.e., the components of the sum of inflow and outflow. The second outmost arcs show the composition of the inflow of each community. The innermost arcs show the composition of the outflow of each community. The inner ring is also made up of three arcs, each of which stands for the total transfer of each community, i.e., the sum of inflow and output (100 million tons). In Figure 1, each chord represents the data of a transfer flow. The chord begins from the source community and ends at the target community and has the same color as the source community. The width of the chord means the size of the

transfer flow. The gaps between the two ends of the chord and the arcs were filled with different colors. The gap at the inflow end is of the same color as the target community, but that at the outflow end is colorless. When two chords intersect each other, the one with the larger flow was placed above the one with the smaller flow.

As shown in Figure 1(a), China's interprovincial virtual water flow network 2002, Community C1, with Xinjiang and Hebei as the core, produced 27.82 billion m^3 of intra-community virtual water flow, about 48.0% and 43.9% of the total transfer-in and transfer-out of that community, respectively. Next comes Community C3, which centers on the Yangtze River Delta, and produces 15.43 billion m^3 of intracommunity virtual water flow, about 34.4% and 33.8% of the total transfer-in and transfer-out of that community, respectively. Centering in Guangdong, Community C2 ranked the third by producing 6.1 billion m^3 of intra-community virtual water flow, about 19.4% and 24.1% of the total transfer-in and transfer-out of that community, respectively. On the national level, the total volume of virtual water within communities amounted to 49.35 billion m^3, accounting for 36.8% of the total virtual water volume in China. These data suggest that China's interprovincial virtual water flow network has significant regional integration. To a certain extent, this reflects the great contributions of Beijing-Tianjin-Hebei Region, Yangtze River Delta, and Pearl River Delta to economic integration. In terms of intercommunity virtual water flows (Figure 1(a)), the intercommunity virtual water flow of China in 2002 stood at 84.92 billion m^3, 63.2% of the total virtual water volume in China. Among them, the largest transfer of virtual water (21.11 billion m^3) was from C1 to C3, taking up 24.9% of intercommunity virtual water flow.

As shown in Figure 1(b), in China's interprovincial virtual water flow network 2007, C2 created the largest intracommunity virtual water flow (29.42 billion m^3), about 46.5% of intracommunity virtual water flow. The internal virtual water flows of C1 and C3 were 27.60 and 61.80 billion m^3, respectively. On the national level, the total volume of virtual water within communities amounted to 63.20 billion m^3, accounting for 37.4% of the total virtual water volume in China. In terms of intercommunity virtual water flows (Figure 1(b)), the intercommunity virtual water flow of China in 2007 stood at 105.65 billion m^3, 62.6% of the total virtual water volume in China. Among them, the largest transfer of virtual water (34.12 billion m^3) was from C1 to C2, taking up 32.3% of intercommunity virtual water flow.

As shown in Figure 1(c), with the expansion of C2, the virtual water flow in that community increased to 55.53 billion m^3 in 2012, 49.2% of intracommunity virtual water flow. When it comes to intercommunity virtual water flows (Figure 1(c)), the intercommunity virtual water flow of China in 2012 rose to 145.44 billion m^3, 56.3% of the total virtual water volume in China. Specifically, the largest transfer of virtual water (38.89 billion m^3) still occurred from C1 to C2, taking up 26.7% of intercommunity virtual water flow.

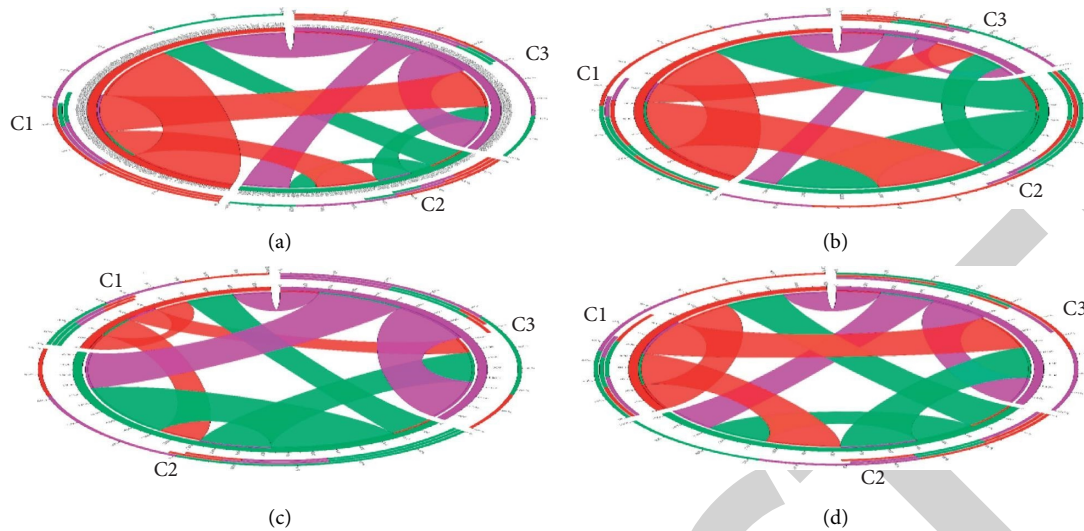As shown in Figure 1(d), in China's interprovincial virtual water flow network 2015, the intracommunity virtual

Figure 1: Intercommunity and intracommunity virtual water flows in (a) 2002; (b) 2007; (c) 2012; (d) 2015.

water flow dropped across the board to 72.56 billion m³, only 32.3% of China's virtual water volume. Correspondingly, C1–C3 had comparable internal virtual water flows: 24.30, 24.36, and 23.90 billion m³. In terms of intercommunity virtual water flow (Figure 1(d)), the intercommunity virtual water flow of China in 2015 was 151.86 billion m³, 67.7% of the total virtual water volume in China. C1 boasted the largest virtual water outflow (61.08 billion m³), 67.7% of China's virtual water flow; C3 saw the largest virtual water inflow (61.49 billion m³), 40.5% of all intercommunity virtual water flow in China. The reasons for the change of transfer flow can be explained from the geographical distance, trade links, and the development strategy of national regional integration. For example, C1 community is a C2 community with Xinjiang as the core and the main agricultural and sideline food production place but with Guangdong as the core. It has developed economy, high living standard, and large per capita food consumption. It needs to buy food and other products from other regions to meet its own needs. Therefore, virtual water tends to flow from C1 community to C2 community.

4. Conclusions

Based on the water-extended MRIO model, this paper calculates the virtual water flows between China's provinces and adopts the complex network theory to analyze the features and evolution trend of China's interprovincial virtual water flow network. In this article, the author analyzed the pattern and evolutionary features of China's interprovincial virtual water flow network. In China's interprovincial virtual water network, Anhui, Xinjiang, Hebei, Jiangsu, and Guangdong dominate, and China's virtual water network can be generally divided into three communities with Beijing-Tianjin-Hebei economic circle, Yangtze River Delta economic circle, and Pearl River Delta

economic circle as the core, and the regional distribution of the communities is generally consistent with the geographical distribution of the provinces covered. To some extent, it confirms the theory of trade gravity. At the same time, China's virtual water network presents the characteristics of regional integration, forming the trend of "three pillars."

The main conclusions are as follows:

(1) From 2002 to 2015, the total virtual water implied in interprovincial trade of China increased from 134.27 billion m³ to 224.42 billion m³, a cumulative growth of 67.1%. Each year, about 29–42% of water resources were consumed to produce export goods. This contributes greatly to the rising total water consumption in China. The interprovincial virtual water in China is mainly affected by the final demand for the products of AFAF, FMP, construction, and service industry.

(2) In the total virtual water volume of China, 25.4% was transferred from North China to South China via trade, while only 22.3% was transferred the other way round. Overall, North China transferred 3.1% of all virtual water to South China. The water resources are out of balance between northern and southern regions in China. Therefore, the flow of virtual water transfers a huge amount of water resource pressure between the two regions. The water resource pressure transferred from south to north is more than 7 times that transferred from north to south. Hence, the virtual water transfer induced by interprovincial trade brings a sizable water resource pressure from South China to North China, which further aggravates the water shortage in the northern region.

(3) Anhui, Xinjiang, Hebei, Jiangsu, and Guangdong dominate China's interprovincial virtual water flow

network. The network can be roughly divided into three communities, which, respectively, centers on Beijing-Tianjin-Hebei Region, Yangtze River Delta, and Pearl River Delta. The regional distribution of the communities is basically consistent with the geographical distribution of the relevant provinces, a proof of the gravity theory of trade. Overall, China's interprovincial virtual water flow network exhibited a multipolar trend. Three centers could be observed in the network, namely, North China, East China, and South China, which signifies regional integration.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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