**JOURNAL OF ADVANCED MECHANICAL ENGINEERING APPLICATIONS**
e-ISSN: 2716-6201

Vol. 6 No. 1 (2025) 14-21
https://publisher.uthm.edu.my/ojs/index.php/jamea

**JAMEA**

# Comprehensive Study on Impact of Inserted Nanoparticles with Base Fluid on Heat Transfer Enhancement in Various Configurations

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DOI: https://doi.org/10.30880/jamea.2025.06.01.002

**Article Info**

Received: 11 November 2024
Accepted: 9 June 2025
Available online: 30 June 2025

**Keywords**

Base fluid, heat transfer, nanofluid, thermal conductivity, enhancement

**Abstract**

Many industrial and engineering applications have low thermal conductivity that affects heating or cooling processes, so the heat transfer process for these applications will be optimized by using small nanometer-sized particles such as metal, oxide, carbide, etc. dispersed in the basic fluid of the application, these particles are called nanofluids. This paper reviews the varying factors affecting the thermal conductivity of various nanomaterials under different conditions. All the authors focused on the thermal conductivity of nanoparticles to increase the heat transfer process, whereby increasing the percentage of nanoparticles, the thermal conductivity increases, and therefore the performance and efficiency of thermal systems increases. The size, shape, collision, aggregation, porous layer, melting point of nanoparticles, etc. are all parameters that affect the thermal conductivity of the nanomaterial, and their control determines the behavior of its increase or decrease. The use of nanofluid is a new and influential technology to improve heat transfer for the next generation. The results of the study indicated that the nanomaterial has an effect on increasing thermal conductivity by significantly raising the efficiency of thermal conductivity of the liquid and improving thermal convection, where the Brownian motion of nanoparticles contributes to improving thermal convection inside the liquid as well as reducing thermal resistance.

## 1. Introduction

Nanoparticles are metal particles with a small size nanometer contained in a nanofluid mixed with water, ethylene glycol, and oil as examples of the basic fluid with a coefficient of convective heat transfer and low conductivity compared to a nanofluid made of metals, carbides, oxides or carbon nanotubes. Nanofluid is intended for the manufacture of a new type of fluid for heat transfer medium by suspending the volume (1 to 100 nanometers) of nanoparticles with a basic liquid such as (pure water, oil, ethylene glycol, etc.). Nanofluids have higher thermal properties compared to conventional liquids, such as thermal conductivity, this is what many researchers have found in recent years. Nanofluids give good opportunities to improve the rate of heat transfer unlike conventional liquids, so it can be observed that nanofluids act as a working medium for heat transfer in various applications. In general, nanomaterials significantly enhance heat transfer in heat exchangers by improving the thermal and rheological properties of the fluid used in them, as follows:

- Raising the effective thermal conductivity of liquids.
- Improved convective heat transfer.

- More uniform thermal distribution.
- Reducing the size of the exchangers or increasing the heat load by the same size.

For example, in HVAC or solar systems, a nanofluid can be used instead of water to improve heat transfer by up to (20-50%) or more, depending on the type, size and concentration of the nanoparticles.

## 2. Nanofluid Production Methods

There are two techniques for preparing nanofluid to improve heat transfer, the first is called the one-step and two-step method. The production of nanoparticles in the first step and their dispersion by the main fluid is the second step. Using the Internet gas condensation technique to mass-produce nanofluid is another processing technique. The shape of the mass during the preparation of nanoparticles is one of the drawbacks of the first two-step technique. In the two-step method of creating nanofluids, the evaporated solid sample is condensed to create nanoparticles in the form of a dry powder. An inert gas is present when the condensation process is carried out. When creating metal oxide nanoparticles, inert gas aids in avoiding the production of metal oxide; if this isn't possible, oxygen gas is used in its stead. Once the nanoparticles are formed, they are distributed throughout the base fluid. The method is employed in two steps for large-scale manufacturing. Because of the strong Van der Waal force, there is a chance that nanoparticles will form clusters during dispersion in base fluid Using a one-step approach, liquid chemical, and physical vapor deposition are used to deposit nanoparticles directly into base fluid. Because this process eliminates the possibilities of nanoparticle storage, drying, transfer, and dispersion, it reduces nanoparticle accumulation and promotes suspension stability. The primary drawbacks of this method are that it can only be used to base fluids with low vapor pressure and that it cannot be scaled up or down for use in industrial settings [1, 2].

## 3. Requirements for Nanofluid

- The minimum pressure value decreases due to the molecular size of the nanofluid.
- Increased heat transfer rate due to the high thermal conductivity of nanoparticles.
- The advantages of using nanofluids in heat exchangers are that they are lightweight and small.
- Mixing the nanofluid with the basic fluid changes its thermophysical properties.
- The large surface volume causes an increase in the heat transfer rate of the main fluid.
- To achieve a heating or cooling system using a nanofluid is best suited.

Experts face the most important challenges for heat transfer by reducing the size of the heat exchanger and increasing the heat flow for efficient energy use. To provide a cleaner and more efficient use of energy in many engineering and industrial applications, nanotechnology is used. Nanofluids can be used in a variety of industries, from transportation to energy production, as well as in electronics systems, for example, microprocessors. When comparing conventional fluids with the new and advanced concept of coolant, it offers interesting heat transfer properties. In industries, several different factors hinder nanofluids, including increased pumping power and pressure drop, long-term stability, in the turbulent and developing region, thermal performance of nanofluids, high cost, and low specific heat.

## 4. Uses of Nanofluid

The nanofluid flows through small passages to improve efficiency and is therefore used in welding equipment, high heat flow devices, heat exchangers, and also in car engines for cooling. Common uses of nanofluid for some engineering industrial applications are as follows:

- Cooling in engine types.
- Transmission and engine oils for vehicles.
- Cooling in electronic and electrical devices.
- Nuclear cooling systems.
- The use of solar energy for water heating.
- In general lubrication and drilling operations.
- Thermal storage systems.
- Applications of Biomedical.
- Flue gas recovery of exhaust boiler.

For nuclear applications, it is helpful to quantify the nanofluid critical heat flow in a forced convection loop. In the US alone, 320 billion kWh of electricity, or the equivalent of 5.5 million barrels of oil would be saved annually if nanofluid increased the chiller's efficiency by 1%. The possibility for deep drilling operations is seen in the nanofluids. By distributing nano diamond particles, a nanofluid may also be employed to extend the dielectric strength and life of transformer oil.

## 5. Previous Literature

Dongdong Li et al. [3] performed an experimental study to investigate the flow and heat transfer properties of a pipe using distilled water as the working fluid. Addition of concentrations (0.1% to 2%) with a volume of (30 nm) of nanofluid particles (CuO) with distilled water to improve its thermophysical properties. The results of the study showed the temperature of the nanofluid is lower for start-up and the start-up time of the evaporation section of the tube is short compared to distilled water. The heat transfer performance of distilled water improved in the condenser and evaporation section of the pipe. The heat transfer coefficient increased by (29.4 %) and (125%) at the concentration of the mass of nanoparticles by (0.5%) with the addition of nanofluid compared to the tube with distilled water and the input power ranges (15 - 45)Watts. The results also indicated that when using nanofluid particles at a concentration of (1%) gave the best improvement of the heat transfer process in the tube.

Byung-Hee Chun et al. [4] presented an experimental study exploring increasing the heat transfer rate by adding alumina particles with transformer oil used as a working fluid in a single-phase laminar flow double-tube heat exchanger system. Although the thermal conductivity of alumina is not high compared to other nanomaterials, it gave a noticeable increase in the rate of heat transfer of the base fluid. By increasing the mass concentration of alumina nanoparticles, the thermal conductivity increases, thereby giving good thermal properties to raise the heat transfer rate of the system. An experimental Association of alumina oil and transducers has been proposed to understand the enhanced heat transfer of nanofluids.

A. M. Elfaghi and M. S. M. Hisyammudden [5] performed a numerical modeling by using the Ansys Fluent program to analyze the use of titanium oxide ($TiO_2$) at a concentration of (0.5%) by adding it with water in a circular tube to improve the thermophysical properties of single-phase turbulent flow for the Reynolds number range (7000-16000) of the tube wall shed with constant and continuous heat flux. According to the numerical results, the efficiency of heat transfer (represented by the Nusselt number) gradually increases with increasing the Reynolds number, so the use of nanoparticles significantly improves the heat transfer of the convection tube compared to the empty tube (without nanoparticles). Two models of turbulent flow were used, the first (k-epsilon) and the second (k-omega). the superiority of the first model in terms of accuracy of results and analysis was noted.

Abdulhafid MA Elfaghi and Musfirah Mustaffa [6] numerical analysis using commercial code (Ansys fluent software) to improve the flow properties of the fluid inside a tube used with a regular thermal overflow. Nanoparticles ($Al_2O_3$) with different volume concentrations (0.5,1, and 2 %) were used to add them to the base fluid (water) to increase heat transfer. Several parameters have been studied, including the heat transfer coefficient, Nusselt number, and friction factor of the nanofluid as a function against the Reynolds number. The results of the study indicated that (11.8%) nanofluids have better thermal performance than the basic fluid. As the concentrations of the nanomaterial increase, the Reynolds number increases and is accompanied by an increase in heat transfer (Nusselt number). A comparison of the results of the study with previous studies in the same field showed a good convergence.

Reza Aghayari et al. [7] presented an experimental study to predict the effect of adding $Al_2O_3$ nanoparticles with a volume of (20nm) and a concentration of (0.1-0.3%) with stable single-phase fluid flow in a double-tube heat exchanger. Various parameters of heat transfer (Nusselt number change) have been studied, including the temperature and concentration of the nanofluid. There is an accepted agreement to compare the results of the study with the correct theoretical data based on quasi-empirical equations. The experimental results showed a significant increase up to (19%) and (24%) for the coefficient of heat transfer by forced convection and the Nusselt number, respectively. It is also observed that as the concentration of nanoparticles increases and the operating temperature, the heat transfer coefficient of the system increases.

M. R. Sohel et al. [8] presented an experimental investigation of the thermal performance of a microchannel using nanofluid instead of pure water with a range of fractional sizes (0.1-0.25%). The different flow rates of the coolant on the overall thermal performance were checked. The working ranges are for the flow rate (0.5 -1.25 L/min) and the Reynolds number range (395-989). Thermal performance improved by using nanofluid instead of pure distilled water, this is what the experimental results showed. Also, the coefficient of heat transfer by forced convection improved higher than (18%) successfully.

Shung-Weng Kang et al. [9] an experimental study employing nanoparticles (Ag) with a molecular size (10 nm) with the basic fluid (pure water) of a horizontal tube with a heated wall. Because of this, the nanofluid's improved thermal performance has demonstrated its potential to replace traditional pure water in grooved heat pipes. The results also indicated the temperature distribution of the surface of the tube gradually decreased towards the axis of fluid flow and with different concentrations of nanoparticles.

Khalid Faisal Sultan et al. [10] experimental evaluation of increased heat transfer of a car radiator by using aluminum and copper nanoparticles with sizes (50 nm) and (30 Nm), respectively, by mixing them with pure distilled water. Various parameters have been studied, including the temperature at which the nanofluid enters, the friction factor, and the Reynolds number, as they affect the heat transfer process. The results indicated that the number of nucleates gradually increases by increasing the Reynolds number, by increasing the concentrations of nanoparticles, and also by increasing the degree of entry of the nanomaterial. Improved heat transfer using copper gave an advantage over aluminum. The findings also showed that employing nanofluid as the working fluid improves heat transfer efficiency, which boosts vehicle engine performance and lowers fuel consumption. Additionally, because of the size of the nanoparticles and the thermal conductivity of the copper, the thermal conductivity of the nanofluids copper was higher than that of the nanofluids aluminum.

N. K. Chavda [11] presented an experimental evaluation of the improvement of the heat transfer properties of a double-tube heat exchanger by changing the concentrations (0.002% to 0.004 %) of nanoparticles (CuO) mixed with water. The study's total heat transfer coefficient increases as the volume concentration of nanoparticles relative to water increases, a finding that is also supported by theoretical predictions.

K. N. Shukla et al. [12] conducted an experimental study to improve the thermal performance of a tube with a length (400 mm) and a diameter (19.5 mm) by adding three different types of nanoparticles (silver, copper, and de-ionized) tested at different ranges of heat input (100-250 W). Using nanofluids, the results of the study showed the thermal efficiency of the tube improved by (14 %) compared to the tube with the basic fluid only. Additionally, it was discovered that a rise in the metal content of copper-water nanofluids improved the heat pipe's thermal efficiency.

J. Choi, and Y. Zhang [13] conducted a numerical study of heat transfer in a curved return tube in which nanoparticles ($Al_2O_3$) were used with the basic fluid with single-phase laminar flow to increase the rate of heat transfer. The finite element method was used to perform numerical analysis. The numerical results showed an increase in the Nusselt number rate (heat transfer rate) by increasing the Reynolds number and the Prandtl number, and also the heat transfer process increased as a result of increasing the specific heat of the nanomaterial. In the case of the Finite Element Method, the grids on the pipe consist of nodal points 5226 and elements 4875; in the case of the CFX with fine mesh, the grids consist of nodal points 292800 and elements 301701. There have been 25 simulations done in all, with concentrations of 0.0%, 2.5%, 5.0%, 7.5%, and 10% with Reynolds numbers of 10, 25, 50, 75, and 100. The numerical results of the curved tube were compared and gave the best improvement against the straight tube, as well as exploring empirical relationships of the rate of the Nusselt number against the Dean and Prandtl number.

S. H. Anilkumar and G. Jilani [14] examined the improvement of heat transmission and the flow properties of the ($Al_2O_3$-Water) nanofluid utilizing a microchannel heat sink. The test section's dimensions are (5x5 mm), and (50W) of heat is applied. When there is a high concentration of nanofluid and a high Reynolds number, heat transmission is improved because the wall temperature drops and the pressure increases.

M. Rostamani et al. [15] conducted a numerical analysis of the optimization of heat transfer of a two-dimensional rectangular channel with turbulent single-phase flow and with a water-factor fluid. Three different nanoparticles were used, including copper oxide, alumina oxide, and titanium oxide in variable volume ratios. All thermophysical properties of nanomaterials are temperature-dependent except for viscosity obtained from experimental data. The results indicated improved heat transfer of the channel by increasing the volume ratio. Copper oxide gave the best enhancement of heat transfer compared to other used nanofluids.

T. Menlik et al. [16] conducted an experimental investigation of how the addition of MgO nanoparticles affects the flow and heat transfer properties of a pipe with a diameter of 13 mm, a length of (1 m), and a wall thickness of 2 mm. The nanomaterial is equipped with a volume ratio (44.5 ml). To cool the system, three distinct cooling water flow rates (5, 7.5, and 10 g/s) were employed in the condenser during the trials, along with three distinct heating power levels (200, 300, and 400 W). The improvement ratio changed in response to changes in heat loads and condenser cooling water flow rates.

A. M. Elfaghi et al. [17] presented a numerical simulation of computational fluid dynamics using the ANSYS program to improve the coefficient of heat transfer by forced convection of a circular tube with turbulent flow for the Reynolds number range (6000 to 12000) by mixing nanoparticles represented by alumina oxide with the basic fluid (distilled water). Several parameters studied as a function against the Reynolds number are the heat transfer coefficient, the Nusselt number, the friction factor, the surface temperature, and the fractional volume fractions (0.5, 1, 2 %). The results recorded the mixing of nanoparticles with water higher the best improvement of the heat transfer coefficient compared to the placement of distilled water alone in the tube. Heat transfer (Nusselt number) gradually increased by increasing the fluid velocity (Reynolds number) and increasing the fractional volume ratios of the nanofluid.

Shung-Wen Kang et al. [18] an experimental investigation to measure the temperature distribution of a tube in which silver is included as a nanofluid to improve thermal performance instead of water. At a temperature of (40 °C), the water-cooled heatsink supplied with a bath and connected to the condenser section of the heat pipe was maintained. By increasing the concentration and size of silver nanoparticles, the thermal resistance of the tube decreases, as shown by the experimental results.

Noor F. A. Hamza and Sattar Aljabair [19] numerical and experimental studies to improve the heat transfer process and flow characteristics of distilled water passing in a horizontal circular three-dimensional tube with turbulent flow in the Reynolds number range (3560-8320). Two optimization methods were used, the first was the addition of a hybrid nanofluid ($CuO+Al_2O_3$) at different volumetric concentrations (0.6, 1.22, and 1.8%) and the second was the insertion of a twisted tape inside the tube. The results of the study showed an improvement in the Nusselt number using these techniques with an empty tube at a volumetric concentration (1.8%).

Marjan Goodarzi et al. [20] studied the experimental realization of a double-tube heat exchanger in which nanoparticles (nitrogen-doped graphene) were used to improve the thermophysical properties of the base fluid and to analyze the total coefficient of heat transfer by forced convection, compressive strength and reduce the wall temperature. The MATLAB program was used to calculate the Reynolds number range (5000-15000) with turbulent flow and the weight ratio of the nanomaterial (0.0 - 0.06%). Experimental results indicated the heat transfer rate improves by increasing the percentage and increasing the Reynolds number. The rate of heat transfer by forced convection is improved by (15.86%) when using nanoparticles by weight (0.06%) compared to using water only.

M. A. Akhavan-Behabadi et al. [21] performed an experimental study to examine the heat transfer of nanofluid flow in a vertical spiral coiled tube at the thermal Inlet. To obtain an isothermal boundary condition, a temperature of 95 degrees Celsius was maintained for the pipe wall. A variety of parameters have been studied for their effect on nanofluids, including the Reynolds and Dean number, as well as geometric parameters, fractions, and weight. Pure heat transfer oil and nanofluids were used as working fluid at weight concentrations (0.1-0.4%) to investigate the effect of liquid type on heat transfer. The experimental data indicates that the heat transmission rate is significantly increased when helical coiled tubes are used in place of straight ones. In addition, Nusselt values for nanofluid flows were significantly greater than those for base fluid flows. Ultimately, it was shown that the two boosting techniques together had a remarkably large capacity to increase the rate of heat transmission.

M. A. Ahmed et al. [22] investigated numerically of the flow of a nanoscale liquid with a weight volume (0-5%) inserted with water by laminar flow of a three-dimensional wavy channel with a Reynolds number range (100-800). Using the finite difference method, the flow governing equations represented by mass, momentum and energy are solved. The local skin-friction coefficient, the local and average Nusselt numbers, and the heat transfer enhancement are shown and analyzed in relation to the nanoparticle volume fraction, the wavy channel amplitude and wavelength, and the Reynolds number. The friction coefficient and Nusselt number rise in proportion to the amplitude of the wavy channel, according to the results. There is only a minor increase in the friction coefficient along with a large increase in the Nusselt number when the nanoparticle volume percentage rises. It was also discovered that, as opposed to wavelength, the augmentation in heat transfer is mostly dependent on the nanoparticle volume percentage, the amplitude of the wavy wall, and the Reynolds number.

Sarmad A. Ali [23] conducted a numerical study using a commercial numerical fluid program based on the finite volume method to enhance forced convection heat transfer in a backward facing step channel by mixing different volume fractions of a nanomaterial (FMWCNT)with pure water with turbulent flow at ranges of Reynolds numbers (10000-18000) single-phase stable two-dimensional. The numerical results indicated that the heat transfer represented by the Nusselt number increases with increasing volumetric fractions, and this occurs as a result of increasing the number of thermally active particles in the liquid and flattening the effective thermal conductivity of the liquid.

Yuxi Yu et al. [24] presented a study in which he showed that hybrid nanofluids, such as those containing a mixture of Ag-Cu or Au-Cu particles, provide noticeable improvements in thermal conductivity of up to 34.3% compared to mono-nanofluids. This improvement is attributed to the effects of Brownian motion and particle distribution, which reduces particle aggregation and enhances thermal conductivity.

In the end, recent research shows that the use of nanoparticles, both single and hybrid, can significantly enhance the efficiency of heat transfer in basic fluids. However, this requires careful balancing between improving thermal performance and the challenges associated with viscosity, stability, and environmental impacts. Research in this area continues to develop innovative and sustainable solutions that meet the needs of advanced industrial applications.

Methods for optimizing the topological shape of microchannel coolers were developed by the researcher Chih-Hsiang Chen and Kentaro Yaji [25] using nanofluids, which led to improvements in thermal performance by up to 11.6% compared to conventional designs. This approach is based on simulating the interactions of particles and liquids to achieve an optimal distribution of heat flow.

Mahdi Mahamed and Seyyedmeysam Seyyedbarzegar [26] presented a study in which studies showed that the addition of $Al_2O_3$ nanoparticles to liquid nitrogen used for cooling superconducting transformers can reduce the temperature of hot spots by up to 52% during fault conditions, which improves cooling efficiency and reduces the risk of thermal failure.

This paper reviews the various thermal properties of nanofluids and other rheological properties and also examines other difficult issues that need to be solved for future research on nanofluids, such as thermal achievement rate, availability, environmental impact, and Economics, in addition to the proposed proposals to ensure more stability of nanofluids over a long period with negligible agglomeration and without changing the properties of liquids chemically during the preparation of nanofluids.

## 6. Discussions

Many authors in their experimental and numerical research papers use nanoparticles ($Al_2O_3$, ZnO, $TiO_2$, Ag, $ZrO_2$, SiC, CuO, and diamond) in various engineering and industrial applications as a technique to improve the heat transfer process (represented by increasing the Nusselt number) and thus increase the performance and efficiency of thermal systems. Many discussed the use of the most common nanoparticles (CuO and $Al_2O_3$) causing increased thermal conductivity of the basic fluid. To enhance the thermal conductivity of nanoparticles an important ultrasonic mixing is used. Nanomaterials play an important role in improving the thermal performance of systems due to their unique physical properties at the nanoscale (usually less than 100 nm) as follows:

1. Increased thermal conductivity**:**
   - Nanoparticles (e.g., aluminum oxide $Al_2O_3$, copper Cu, or nanocarbon) when added to fluids (e.g., water or oils), form what are known as nanofluids (Nanofluids).
   - These nanofluids exhibit a much higher thermal conductivity than conventional liquids, which improves heat transfer in heat exchangers, cooling systems, and others. Example: a nanofluid containing copper nanoparticles can improve the thermal conductivity of water by up to 40% or more.
2. Increased surface area**:**
   - Nanomaterials have a high surface-to-volume ratio, which means they have a very large surface area compared to their size.
   - This property facilitates faster and more efficient heat exchange between the nanomaterial and the surrounding medium.
3. Improvement of convection (Convection):
   - Nanoparticles can improve the convection properties in liquids, by provoking a disturbance in the near-surface liquid layer, which enhances the heat transfer.
4. Reduce thermal resistance:
   - When used in building materials or insulation systems, nanocomposites can reduce thermal resistance between different layers, allowing faster heat transfer.
5. Specially designed thermal properties:
   - Nanomaterials can be designed to have custom thermal properties, such as phase-change (PCM) materials reinforced with nanoparticles to store and release heat more efficiently.

## 7. Conclusions

- Increased concentrations in nanoparticles increase the rate of heat transfer.
- Using a nanofluid the heat transfer rate is directly proportional to the Nusselt number and Peclet.
- In nanofluids the Nusselt number (heat transfer rate) increases by increasing the Reynolds number as a result of directly proportional.
- The microarray of the nanoparticles suffers from poor stability but increases the heat transfer rate of the system.
- The main influencing factor of the nanofluid is increasing the heat transfer rate due to the aggregation and collision of various particles.
- The pressure in the nanofluid decreases with an increase in the percentage concentration of nanoparticles.
- The spherical shape of the particles in nanomaterials significantly increases the rate of heat transfer when mixed with the basic fluid compared to other shapes of molecules.
- Nanomaterials added with spiral tubes significantly improve the heat transfer rate compared to plain tubes with a circular cross-section.
- The decrease in the value of pressure in inclined tubes filled with nanofluid is higher compared to horizontal tubes.
- The nanomaterial has an effect on increasing thermal conductivity by significantly raising the efficiency of thermal conductivity of the liquid and improving thermal convection, where the Brownian motion of nanoparticles contributes to improving thermal convection inside the liquid as well as reducing thermal resisting, where when using nanomaterials in thermal contact interfaces reduces the micro-gaps between surfaces, which improves heat transfer.

The current study proposes to explore the effect of mixing multiple types of nanoparticles (hybrid nanomaterials) with various basic fluids (such as water, ethylene, glycol, and thermal oils) to improve the performance of forced convection heat transfer, through theoretical, numerical, and experimental analysis).

## Acknowledgements

The authors would like to thank the Department of Automotive Engineering at the University of Babylon for their support in completing the current study (https://engmsy.uobabylon.edu.iq/ ).

## Conflict of Interest

Regarding the paper's publication, the authors affirm that they have no conflicts of interest.

## Author Contribution

*The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.*

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