Theoretical modeling and machining experiments of cylindrical microstructure assisted by single-point diamond turning

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Abstract
Microstructure requires nanometer-scale surface roughness and micro- or even sub-micron form error accuracy in different applications. Two kinds of modeling theories and methods of micro-feature of rotating body and non-rotating body are studied, and the corresponding tool turning trajectory planning method is put forward. In order to process the designed micro-feature structure successfully and avoid the interference and overcutting between tool and workpiece caused by improper selection of tool parameters, the cutting parameters are analyzed and two error theories are proposed. Then, a precision-driven turning trajectory planning method is obtained, which can optimize the trajectory by adjusting turning parameters according to the setting errors. The experiments are carried out to verify the proposed theories, and the results of measurements are that the surface roughness and surface form accuracy of the cylindrical sine wave groove micro-feature surface are 0.1714 μm and 1.32 μm, respectively. The surface roughness and surface form accuracy of the cylindrical sinusoidal mesh micro-feature surface are 0.1625 μm and 1.8 μm, respectively. The results meet expectations and verify the reliability of the error theory and the trajectory optimization theory.

Keywords Cylindrical sine wave groove micro-feature surface (CSWGS) · Cylindrical sinusoidal mesh micro-feature surface (CSMS) · Single-point diamond turning · Micro-feature surface modeling · Turning trajectory planning · Error theories

1 Introduction

It is of great significance to analyze and research micro-features because it plays an important role in application to optics, biomimetics, medicine, communication, and other fields. Recent advances in four reflective optical systems and optical lens always depend on the surface topographies and qualities of micro-features to achieve better optical paths and benefits. In many other cases, the accuracy of micro-feature surface needs to reach the accuracy of nanometer surface roughness and micron or even sub-micron form error, which has become a focus of research for experts and scholars in related fields all over the world.

Many researchers have done a lot of studies in the field of cylindrical micro-feature processing and error analysis. Dai et al. [1] studied the influence of tool deviation at the center of the spherical surface and established a force-based tool deviation model, and they predicted the 3D form of the surface online. Gao et al. [2] proposed a method for adjusting the position of a tool in fast tool servo turning of the cylindrical outer circle. Lu et al. [3] studied that when the rear angle of the tool is less than the critical value of the characteristic, and they proposed a theoretical calculation model to calculate the wavelength and amplitude of the slot caused by the interference between the tool and the workpiece in the fast tool servo turning of the micro-feature. Tauhiduzzaman et al. [4] studied the form error in diamond turning, and they thought the relative vibration between cutting tool and workpiece is the main cause of the error, and it is pointed out that the unbalanced
spindle of the machine tool has the most influence on machining of feature curved surface. Chen et al. [5] studied a method of measuring micro-feature defects in fast tool servo lathe in real time, and the thrust force map was obtained by force sensor fluctuates abnormally and the defects were located, and then the micro-feature repair was carried out by a more accurate tool path. Mak et al. [6] studied the effect of single-point diamond turning on the machining accuracy of the V-shaped groove on the high-precision drum surface using different processing strategies, and they optimized the processing parameters including the turning depth and the turning times. Kong et al. [7] used single-point diamond turning with orthogonal slow tool servo technology to process the corrugated micro-structure on the high-precision cylindrical surface under the 9 sets of different processing parameters. Mukaida et al. [8] used slow tool servo diamond turning technology to process micro-lens array on single silicon material, and they studied the machining form error, surface morphology, and turning force experimentally. Zhang et al. [9] studied the turning of cylindrical Fresnel lens as a die for pressing the Phoenix lens on the flexible matrix roll, and the cylindrical Fresnel lens was turned in both radial and axial directions of cylinders by four-axis linkage. Zhang et al. [10] analyzed the center error caused by the deviation between the tool height and the spindle axis, and it could form a cone or cylinder boundary when the deviation appears. To determine and explore the tool interference, they built a mathematical model and did some experiments, which have meaningful influence for controlling error. Wang et al. [11] proposed a scanning method for high-gradient free-form surface, which can generate a mesh measuring path controlled by the planning deviation, and it has been verified by experiments.

As can be seen from the above, there are many studies about how to improve surface quality during processing free surface on the plane but few researches about how to control the surface accuracy during processing free surface on the cylinder. In this study, a precision-driven turning trajectory planning method and two cutting error theories were proposed with experimental verification. Based on the methods and theories, the designed micro-feature structure of rotating body and non-rotating body can be processed successfully with optimized turning parameters while ensuring that the two errors are within control. Besides, how to choose suitable tool parameters was studied to eliminate the interference and overcutting between the tool and workpiece. The remaining part of this paper is arranged as follows: Modeling analysis is illustrated in Section 2. The tool parameter selection is described in Section 3. The error control theory of micro-feature processing is proposed in Section 4. The tool radius compensation is shown in Section 5. The experiments and corresponding results are presented in Section 6. Finally, conclusions are drawn in Section 7.

2 Modeling of cylindrical microstructures

There are many modeling methods for cylindrical microstructures; the two main methods are reverse modeling and forward modeling, and this paper mainly studies the forward modeling method. In this study, according to the forward modeling method of cylindrical microstructures, the theoretical models of cylindrical sine wave groove micro-feature surface (CSWGS) and cylindrical sinusoidal mesh micro-feature surface (CSMS) are carried out.

As shown in Table 1, the CSWGS is obtained by the combination of cylinder surface and axial sinusoidal line. CSWGS is a rotating body, whose bus line equation is Eq. (1), where \( R \) means the radius of the cylindrical body and \( f_1(z) \) means the distance from each point to the axis of the body.

The CSMS is a non-rotating body, which is obtained by the combination of CSWGS and radial sinusoidal feature surface. And the equation of radial sinusoidal feature surface is Eq. (2), where \( f_2(\theta) \) means the radial variation related to the angle \( \theta \). Based on the combination of Eqs. (1) and (2), the distance from each point to the axis of the body can be expressed by Eq. (3). Then, the cylindrical coordinates are converted to the Cartesian coordinates by Eq. (4) to obtain the discrete coordinate points, where the coordinate of the \( i \)th coordinate point is \((x_i, y_i, z_i)\), \( \Delta z \) is the vertical distance of each two points of the cylindrical spiral trajectory, and \( i \) is the number of coordinate points.

\[
\begin{align*}
1) \quad & f_1(z) = h \cdot \sin(\omega \cdot z) + R \\
2) \quad & f_2(\theta) = R_1 \cdot (h_1 + h_2 \cdot \sin(\omega_1 \cdot \theta)) \\
3) \quad & f_3(\theta, z) = f_1(z) + f_2(\theta) \\
4) \quad & \begin{cases} 
   x_i = f_3 \cdot \cos(\theta_i) \\
   y_i = f_3 \cdot \sin(\theta_i) \\
   z_i = \Delta z \cdot i
\end{cases}
\end{align*}
\]

3 The choice of geometric parameters of diamond tools

In order to compensate the tool radius conveniently in the subsequent work, a conical diamond tool is selected. The selection of correct tool parameters is very important for turning. The tool radius \( r \), tool wrap angle \( \alpha \), tool rake angle \( \beta \), and tool rear angle \( \gamma \) are analyzed in this section.

For machining in CSWGS and CSMS tool turning, the principle diagram of diamond turning is displayed in Figs. 1, 2, and 3, respectively. Figures 2 and 4 give the expansion graph about the cutting procedure of CSWGS and CSMS, respectively, and the red track line represents the cutter contact turning trajectory and point \( P_i \) represents the cutter turning contact point.
In the turning process, the tool is fed along the workpiece axis, and the curvature at each point on the micro-feature axial bus needs to be calculated, and then the tool radius is selected. For CSWGS, only the curvature calculation shall be performed for the bus bar. For CSMS, it is required to divide the characteristics within one cycle in the circumferential direction. The dividing angle was set as $\theta$, and then the curve equation $\rho = f(z, \theta_i)$ fitting shall be carried out on the data of the micro-feature surface corresponding to $\theta_0$, $\theta_1$, $\theta_2, \ldots, \theta_n$, where, the radius of $\theta_i$ is constant, $z$ is the variable, and then all turning points on each bus equation shall be calculated to calculate the radius of the curvature and the cutter radius $r$.

The curvature of the curve is calculated as shown in Eq. (5). The tool wrap angle and tool rear angle can be calculated in the same way as the tool radius, whose computational method and mathematical analysis modeling are shown in Table 2.

As shown in Fig. 5a and Fig. 6a, the pitch $l_j$ decides the tool wrap angle $\alpha$ and tool radius $r$, and the direction of turning feed decides the tool rear angle $\gamma$ and tool rake angle $\beta$.

As shown in Fig. 5b, when the selected tool radius $r$ is greater than the curvature radius at a cutting point, the cutting interference occurs, and the larger the tool wrap angle $\alpha$ is, the longer the effective turning edge length of the tool tip is. On the $\gamma$ surface, when the tool radius is $r_2$ and the tool wrap angle $\alpha$ is $\alpha_1$, there is a cutting interference at point $P_{12}$. The wrap angle $\alpha_2$ at point $P_{13}$ is greater than that $\alpha_1$ at point $P_{11}$, and the effective turning edge length is longer.

As shown in Fig. 6b, the selection of tool rear angle $\gamma$ and tool rake angle $\beta$ may affect whether the tool surface interferes with the machined surface. On the $\gamma'$ surface, there is cutting interference at $P_{11}$ and $P_{14}$ points, and the tool rear angle $\gamma_1$ of point $P_{11}$ is too small, and the tool rake angle $\beta_2$ of point $P_{14}$ is too large. The rake angle at point $P_{15}$ is 0.
4 Error control theory of micro-feature processing

The machining error caused by trajectory planning is the most important influence on machining accuracy in the machining process. The establishment of the error model is studied in this chapter, including residual height error and chord error.

4.1 Establishment of the mathematical model of residual height error

Residual height error is caused by the circular arc at the tool tip of the diamond tool. The residual material of workpiece is produced between the adjacent cutter contact points on the turning tracks, resulting in the production of the residual height error ($R_{er}$).

To calculate the residual height error, it is necessary to obtain the characteristic axial curve equation. For a rotating body, it is the bus equation. For a non-rotating body, curve equations need to be obtained by fitting the axial data of curved surfaces. Then, the curvature radius $R_{QL}$ and curvature at the corresponding point are calculated by the axial curve equation, the positive and negative curvature is judged, and the residual height error $R_{er}$ of three different cases is calculated by Eqs. (10)–(12); when the curvature equals zero, the equation is Eq. (10), when the curvature is less than zero (convex), the equation is Eq. (11), and when the curvature is greater than zero (concave), the equation is Eq. (12). The theoretical analysis of the $R_{er}$ is shown in Fig. 7.

While $r$ is the arc radius of the tool tip of the selected tool, $f$ is the axial feed of the tool for each turning workpiece in the machining process, which is pitch. Based on the calculation of the above three cases, the feed $f$ can be reversed by Eqs. (13) and (14).

$$R_{er} = r - \sqrt{r^2 - \left(\frac{f}{2}\right)^2}$$  \hspace{1cm} (10)

$$R_{er} = \sqrt{(RQL + r)^2 - \left(\frac{f}{2}\right)^2 - \sqrt{r^2 - \left(\frac{f}{2}\right)^2}} - RQL$$ \hspace{1cm} (11)

$$R_{er} = RQL - \sqrt{(RQL - r)^2 - \left(\frac{f}{2}\right)^2 - \sqrt{r^2 - \left(\frac{f}{2}\right)^2}}$$ \hspace{1cm} (12)

\[
\left\{ \begin{array}{l}
  f_1 = \sqrt{-R_{er}(R_{er}-2R)(R_{er}-2R)/(R_{er}-R)} \\
  f_2 = 2\sqrt{-R_{er}(R_{er}-2R)} \\
  f_3 = \sqrt{-R_{er}(R_{er}+2R)(R_{er}-2R)/(R_{er}+R)}
\end{array} \right. \hspace{1cm} (13)
\]

$$f = \min\{f_1, f_2, f_3\}$$ \hspace{1cm} (14)

4.2 Establishment of the mathematical theoretical model of chord error

In order to improve the machining accuracy of the cylindrical micro-feature surface, the mathematical theoretical model of chord error ($C_{er}$) is established in this section. The formation position of the chord error is shown in Fig. 8a. Figure 8b shows the mathematical model of chord error calculation, where $L_i$ is the turning step, which is the distance between two adjacent cutter contact points in the turning direction, and $R_i$ is the approximate arc curvature radius of an ideal arc between two adjacent cutter contact points.

According to Fig. 8b, the distance $L_i$ shall be calculated by Eq. (15), where $x, y,$ and $z$ are the coordinates of the cutter contact points of spiral trajectory. After solving the step size, the approximate arc curvature radius $R_i$ needs to be calculated by Eq. (16).

Because the actual turning trajectory is composed of straight line segments, and the turning trajectory is spirally fed on the cylindrical micro-feature surface, so there are three cases of chord error as shown in Fig. 8a.

$$L_i = \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2 + (z_i - z_{i+1})^2}$$  \hspace{1cm} (15)
When the turning trajectory line is on the protruding surface, this situation may cause an overcutting phenomenon, and when the turning trajectory line is on the sunken part of the surface, it may lead to insufficient turning. The chord error \( C_{er} \) can be calculated by Eq. (17). And then, the turning step \( L_i \) can be solved by Eq. (18). Constraining the size of turning step \( L_i \) is essentially a constraint on the radial fraction parameter \( t \).

Chord error:
\[
C_{er} = \sqrt{R^2 - \left( L / 2 \right)^2}
\]

(17)

Turning step:
\[
L_i \leq \sqrt{8R \cdot C_{er} - 4C_{er}^2}
\]

(18)

### 4.3 Trajectory optimization

The mathematical model of cylindrical micro-feature error has been established. Based on the error theories, then the precision-driven turning trajectory planning method can be achieved by the following steps: First, set the initial turning parameters: the axial feed \( f \) and cutting points number per round \( t \) of spiral trajectory, the accuracy of chord error \( C_{er} \), and residual height error \( R_{er} \). Second, the initial trajectory can be generated according to the \( f \) and \( t \). After that, the chord error \( C_{er} \) and the residual height error \( R_{er} \) can be solved by the error theories, and if the errors meet the accuracy, then the turning trajectory planning is completed. If \( R_{er} \) cannot meet the setting accuracy, then adjust the \( f \) and go back to the previous step to recalculate the \( R_{er} \), and if \( C_{er} \) cannot meet the setting accuracy, then adjust the value of \( t \) and reverse to the second step to regenerate new trajectory and chord errors. Then, repeat the above steps until precision meets the requirements and the last optimal trajectory can be obtained.

The schematic diagram of generating the final optimal trajectory through error control is shown in Fig. 9. By controlling the error and adjusting the turning parameters repeatedly, the final turning trajectory is determined and the trajectory optimization is completed.

### 5 Tool radius compensation

The ultra-precision numerical control (NC) lathe needs to input the cutter location points of the turning trajectory, which is based on the cutter contact points to compensate the tool radius in the normal vector direction of each point. The tool radius compensation is to compensate the cutter contact points one by one in the normal vector direction of the cutter contact points, which can get all the cutter location points. Tool radius compensation for rotating bodies such as CSWGS and non-rotating bodies such as CSMS is described in this section.

The angle \( \theta \) is the angle between the normal vector and the Z axis at each point of the micro-feature surface. Let the micro-feature generatrix equation of the rotating body be \( x = f(z) \); then the angle \( \theta \) can be obtained by Eq. (19). By calculating the angle \( \theta \), the tool radius compensation of the
corresponding cutter contact points can be carried out to obtain the cutter location points, which is shown in Eq. (20).

$$\theta = \arctan(f'(z))$$

$$X_i = R_i + r \cdot \cos(\theta_i) \cdot \cos(2 \cdot \pi \cdot i/t)$$

$$Y_i = R_i + r \cdot \cos(\theta_i) \cdot \sin(2 \cdot \pi \cdot i/t)$$

$$Z_i = z_i - r \cdot \sin(\theta_i)$$

While $R_i$ is the distance from each cutter contact point to the axis of the workpiece, the expression is $R_i = \sqrt{(x_i)^2 + (y_i)^2}$.

For cylindrical non-rotating micro-features, another tool radius compensation method is needed; the concrete steps are as follows. First, set the parametric equation of space curve Eq. (21), and then the tangent direction vector $T$ will be calculated by Eq. (22). The first-order derivative and the second-order derivative of $k$ are multiplied to obtain a sub-normal direction vector $B$, which is shown in Eq. (23). At last, the main normal vector $N$ is equal to the cross product of $B$ and $T$ by Eq. (24).

$$k = (a \cdot \cos \alpha, a \cdot \sin \alpha, b \cdot \alpha)$$ (21)
According to Eqs. (21)–(24), the main normal vector $N$ at each cutter contact point on the turning trajectory of the non-rotating body can be calculated, and then the cutter radius compensation can be carried out to obtain the cutter location point.

Based on the calculation method of the cutter contact point and cutter location point of rotating and non-rotating micro-feature described above, the calculation results are obtained as shown in Figs. 10 and 11, and the effectiveness of the above method for solving the micro-feature cutter location points can be verified by experiments.

6 Experiments and discussion

On the basis of optimization selection of tool parameter, turning trajectory planning, error model establishment, and optimization of turning trajectory parameter, two kinds of cylindrical micro-features are machined by the single-point diamond slow cutter servo turning method. The two experiments
are CSWGS experiment of rotary body and CSMS experiment of non-rotating body, respectively.

### 6.1 Turning experiments

The machining errors of cylindrical micro-feature are set to 1 μm, and the geometric parameters of the turning tool are selected as shown in Table 3. The type of precision turning machine is nanoform250 (Precitech Company, Keene, NH, USA), and the main parameters of the machine tool are shown in Table 4. The tool coating is not used; the coolant produced by Briggs & Stratton Company (Milwaukee, WI, USA) was used in this experiment. The trial was repeated three times. The material of workpiece is Al7075, and the diameter of the workpiece is 25 mm, and the length \( L \) of the workpiece is 6 mm.

| Table 3 | Geometric parameters of diamond tools |
|----------|--------------------------------------|
| Tool parameter | Symbol | Parameter values | Units |
| Tool rake angle | \( \beta \) | 0 | ° |
| Tool rear angle | \( \gamma \) | 1 | ° |
| Tool wrap angle | \( \alpha \) | 120 | ° |
| Tool radius | \( r \) | 0.506 | mm |

| Table 4 | Main parameters of the nanoform250 machine tool |
|----------|-----------------------------------------------|
| Main parameters of the machine tool | Parameter values | Units |
| C axis feedback resolution | 0.026 | arc seconds |
| C axis position accuracy | ±1 | arc second |
| C axis maximum speed | 3000 | RPM |
| X, Z axis stroke | 220 | mm |
| X, Z axis straightness | Horizontal full stroke 0.2 | μm |
| Position feedback resolution of linear hydrostatic guideway | 0.016 | nm |
First, the blank is mounted on the fixture to the turning machine, and then the fixture is aligned and the main shaft dynamic balance is adjusted to ensure the machining accuracy. The tool is equipped with an LVDT optical tool alignment device to the tool process. After completing the preparation work, the blank is rough-machined to get the cylindrical surface. After completing the two operations above, the machining trajectory data optimized by the error model are used to transform the Cartesian coordinates into cylindrical coordinates and input them into ultra-precision NC machine tools for micro-feature machining. Next, the finish machining is performed according to the NC code, and the processing times are calculated according to the

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**Table 5** Required parameters of CSWGS

| Parameter name                        | Symbol | Parameter values | Units     |
|---------------------------------------|--------|------------------|-----------|
| Sine wave slot amplitude              | $h$    | 0.04             | mm        |
| Sinusoidal wave                       | $\omega$ | 4                | rad/s     |
| Characteristic radius                 | $R$    | 12.5             | mm        |
| Characteristic length                 | $L$    | 6                | mm        |
| Cutting points number                 | $t$    | 249              | Pts/round |
| Pitch                                 | $f$    | 0.0635           | mm        |

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**Table 6** Required parameters of CSMS

| Parameter name          | Symbol | Parameter values | Units     |
|-------------------------|--------|------------------|-----------|
| Axial amplitude         | $h$    | 0.02             | mm        |
| Axial period            | $\omega$ | 4                | rad/s     |
| Axial feature           | $R$    | 12.2             | mm        |
| First radial amplitude  | $h_1$  | 0.03             | mm        |
| Second radial amplitude | $h_2$  | 0.02             | mm        |
| Radial period           | $\omega_1$ | 12              | rad/s     |
| Radius                  | $R_1$  | 2.5              | mm        |
| Cutting points number   | $t$    | 249              | Pts/round |
| Pitch                   | $f$    | 0.0635           | mm        |
Fig. 14 a–h Measurement and calculation results of CSWGS and CSMS
designed micro-feature surface and cutting depth, and then the approximate processing time is calculated. Only one workpiece is machined for each designed cylindrical microstructure, so two groups of experiments were conducted.

6.2 Measurements and discussions

The roughness measurement of the two machined micro-features is measured by a Talysurf PGI 1240 (Taylor Hobson Company, Leicester, England) instrument, which is shown in Figs. 12 and 13. After processing the measured data, the results of roughness of CSWGS and CSMS are shown in Fig. 14 a and b, and the measured roughness values are 0.1714 μm and 0.1625 μm, respectively.

The surface morphology of CSWGS and CSMS was measured by a KEYENCE vhx900 instrument (Keyence Company, Osaka, Japan), and the measured results are shown in Fig. 14c and d, respectively. The measured data and the theoretical values of CSWGS are shown in Fig. 14e. The radial error band of CSMS is shown in Fig. 14f. The deviation between measured data and theoretical data of CSWGS and CSMS is shown in Fig. 14g and h, and their PV values are 1.32 μm and 1.8 μm, respectively, which have little difference with the setting error.

Experimental results show that all of them have high accuracy, which verifies the theory of trajectory planning, the method of optimizing turning trajectory parameters by error model, and the reliability of micro-features of turning cylindrical and non-rotating body.

7 Conclusions

In this paper, the theory and technology of single-point diamond turning with micro-features of cylindrical surface are studied. The research contents mainly include the optimization selection of geometric parameters of diamond tools, the modeling of cylindrical micro-feature surfaces and the generation principle of tool turning trajectory, the principle of tool radius compensation, and the optimization of machining trajectory parameters by establishing the theoretical model of turning error. The turning experiments of cylindrical sinusoidal groove and non-rotating cylindrical sinusoidal grid of rotating body are carried out by using the nanoform250 ultra-precision machine tool. The Talysurf PGI 1240 instrument is used to measure the precision of workpiece surface, and then the obtained data are processed and analyzed. The machined feature surface morphology is measured by KEYENCE vhx900. The micro characteristic surface roughness (Ra) of CSWGS is 0.1714 μm, and the surface form accuracy is 1.32 μm. The surface roughness of CSMS is 0.1625 μm, and the surface form accuracy is 1.8 μm. All of them have high machining accuracy, which verifies the correctness of the theories proposed in this paper. The purpose of this study is to control the accuracy of machining on cylindrical surfaces, which will make the work efficient for engineers engaged in cylindrical design and processing. In future research, free surface without definite expression should be designed and fabricated on a cylindrical surface. In addition, coupling effects of chord error and residual height error should be comprehensively analyzed in machining. Moreover, the research in this paper is conducted in a relatively ideal state, in actual state, and factors of machining errors are more and complicated; such as plastic deformation and the tool-workpiece vibration should be considered in the future work.

Nomenclature
CSWGS, Cylindrical sine wave groove micro-feature surface; CSMS, Cylindrical sinusoidal mesh micro-feature surface; \( r_i \), Tool radius; \( \alpha \), Tool rake angle; \( \beta \), Tool rear angle; \( \gamma_i \), The pitch of spiral trajectory; \( \text{tk} \), The radial trajectory of \( \gamma_i \) surface; \( \text{tk} \), The turning trajectory; \( \text{Kc} \), Curvature of the curve; \( \text{Rc} \), The curvature radius; \( \text{R_h} \), The residual height error; \( \text{L_p} \), The approximate radius of arc curvature; \( \text{Lt} \), The turning step; \( \text{C_a} \), The chord error; \( \text{f} \), The axial feed; \( \text{t} \), The cutting points number per round; \( \text{k} \), The parametric equation of space curve

Author contribution Jingjin Li contributed to the process and summary of the study and wrote the manuscript. Shijun Ji and Ji Zhao made great guidance on the concept, direction, and experiment of the research. Jingjin Li and Jianfeng Li designed and performed the experiment. Jingjin Li and Handa Dai tested the results and analyzed the data.

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Data availability The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate All authors agreed with the consent to participate.

Consent to publish All authors have read and agreed to the published version of the manuscript.

Competing interests The authors declare no competing interests.

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