Surface modification of Ti-6Al-4 V by gas–liquid mixed EDM

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Abstract

Ti-6Al-4 V alloy is widely used in many fields due to its excellent properties. However, its further applications are limited by its low hardness and poor wear resistance. In this paper, gas–liquid mixed electrical discharge machining (G-LEDM) process was applied to investigate the machining performance and surface modification Ti-6Al-4 V alloy. The effect of peak current and pulse duration on surface morphology, surface roughness, cross section morphology, micro hardness, and wear resistance were investigated using nitrogen mixed special oil dielectric. The results indicated that the G-LEDM process has better performance with fewer pores, shallower and larger craters on smoother surface. A continuous and thicker recast layer was obtained on G-LEDM process. The X-ray diffraction results demonstrated that TiN phase was formed on the sample surface. The micro hardness of G-LEDM process was about 1329.5 HV, which is about 3 times that of the matrix, and the wear resistance is improved accordingly. The surface of Ti-6Al-4 V alloy was modified by G-LEDM process.

Keywords Gas–liquid mixed electrical discharge machining (G-LEDM) · Ti-6Al-4 V · Surface modification · Nitrogen · TiN

1 Introduction

Ti-6Al-4 V alloy has been extensively applied in aerospace, automotive, and biomedical applications owing to its prominent characteristics, including high specific strength and excellent corrosion resistance [1]. Nevertheless, titanium alloy has low hardness and poor wear resistance, which restricts its further application especially in wear and tear engineering [2]. Hence, it is essential to find an effective approach to enhance the mechanical performance of titanium alloy. Titanium alloy is also difficult to process with the traditional method [3]. Electrical discharge machining (EDM) is a non-traditional machining method with no direct contact between the workpiece material and the tool electrode, it makes use of a series of spark energy between electrodes to melt and evaporate materials irrespective of their mechanical properties [4]. However, the EDMed surface of titanium alloy still has poor surface quality like micro cracks and pores, low wear resistance.

To further improve the surface properties of titanium alloy, researchers have attempted many ways to achieve surface modification. Adding different powders in dielectric has been actively used to achieve surface modification. Sharma et al. [5] carried experiments to attain a hard, wear, and corrosion resistance surface using hexagonal boron nitride powder mixed deionized water over micro-electrical discharge coating process. The results showed the hard phases such as BN, TiN, TiAlN formed on the machined surface, which increases the micro hardness by approximately 5 times than the parent material and reduces the wear rate by about 4 times than the parent material. The corrosion rate decreases from 5.92 to 1.24 µm/year in flowing water conditions. Mohanty et al. [6] added tungsten disulphide (WS2) powder in deionized water to explore the impact of different parameters on surface properties. The results indicated that the minimum surface roughness was obtained at lower voltage (20 V), higher powder concentration (12 g/L). The highest micro hardness is about 881.34 HV due to the presence of a hard and solid-lubricating layer on the machined surface. Apart from this, the wear rate was decreased as compared to that of the base material. Bui et al. [7] studied the surface characteristics of Ti-6Al-4 V alloy by adding different concentrations of silver nano-particles into the dielectric. The results revealed that the powder concentration has a significant impact on the coating layer of the silver
content. The silver content in the deposited layer increased with increasing powder concentration, while decreased with increasing depth of the deposited layer, the antibacterial property was also improved owing to an antibacterial layer that was formed on the medical titanium alloy surface. Alam et al. [8] investigated the surface performance of PMEDM process with graphite and titanium oxide powder, respectively. The powder concentration and peak current were varied to study their effect on the material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR). The results showed that titanium oxide powder has a better performance compared to graphite including higher MRR, lower TWR, and smoother surface roughness. Expect for the addition of powders, Yan et al. [9] used 10 g/l of urea and the distilled water as dielectric to explore the feasibility of surface modification of pure titanium. The outcomes indicated that nitrogen element from urea migrated to the machined surface, forming a TiN layer due to the reaction between the workpiece and urea solution, leading to the enhancement of micro hardness and wear resistance.

Kong et al. [10] supplied submersed gas-flushing EDM method to machine Ti-6Al-4 V alloy, they evaluated the effects of different gas (air and argon) on machining characteristics. The results showed that the argon medium provides better surface integrity and higher machining efficiency as compared to the air medium, the relative electrode wear ratio was decreased in the argon medium. However, titanium oxides and nitrides were observed on the machined surface with air medium. Takezawa et al. [11] surveyed the effect of mixing micro bubbles with the dielectric fluid to machine titanium alloy and steel under the finishing condition. The bubble mixed dielectric inject from the electrode bottom face. Their results revealed that the formation of nitride in the steel did not improve the hardness, and for titanium alloy material, the nitrogen micro bubble was not necessary for the generation of nitride. Xu et al. [12] studied the EDM ablation mechanism using oxygen-atomizing dielectric, compared with that of EDM process using argon-atomizing dielectric. The results revealed that the EDM ablation obtained higher discharge possibility and lower short circuit possibility, generating a higher processing efficiency. In addition, they analyzed the ratio of combustion portion and the discharge portion in the EDM ablation, finding that the former accounted for at least 67%. However, the EDM ablation is carried on Cr12 material, and the surface characteristics are not detailedly analyzed.

From the mentioned literatures above, it was found that so many efforts have been made to achieve surface modification of titanium alloy by the addition of different powders or other substance. However, there are few researches on G-LEDM process to machine titanium alloy, especially for the gas medium is nitrogen. Nitrogen is being utilized not only as a medium but also as a reaction gas at high temperatures. The G-LEDM process combines the advantage of gas and liquid processing, the discharge process is more stable when nitrogen is mixed with the special spark oil.

In this paper, the machining properties of Ti-6Al-4 V alloy by G-LEDM process with different parameters were investigated. The effect of gas–liquid mixed dielectric on the machined performance of titanium alloy was studied by injecting nitrogen into the multi-hole electrode and compared with that of pure liquid dielectric. It was expected that the nitrogen could react with titanium alloy to form TiN compound at the elevated temperature and high pressure of EDM discharge, thus G-LEDM process can enhance the machining performance of Ti-6Al-4 V alloy.

### 2 Materials and methods

Ti-6Al-4 V alloy was chosen as the workpiece material with the size of 10 mm × 10 mm × 5 mm, and Table 1 displays its chemical composition. The tool electrode adopted a customized copper tubular electrode (Φ16 mm × 65 mm) with nineteen uniform holes (Φ0.8 mm × 65 mm) allowing nitrogen gas uniform flow, as shown in Fig. 1. The screw thread on the electrode was designed to connect the electrode holder, and the outer diameter of the electrode matched the internal diameter of the electrode holder, which can fix the multi-hole electrode. A kind of special spark oil was considered as the liquid dielectric with good dielectric feature. The properties of nitrogen and special spark oil are shown in Table 2. The nitrogen gas flows from the multi-hole electrode into special spark oil, then they are mixed in the working slot as gas–liquid dielectric.

The experiment was conducted with die-sinking EDM machine (CNC-A30, Rixin Co., Ltd., Dongguan, China). Figure 2(a) shows the experimental schematic, and Fig. 2(b) displays the photograph of experimental set-up. The multi-hole tool electrode was mounted on the processing head through the electrode holder, one side of the electrode holder is also the inlet of nitrogen, nitrogen as the gas dielectric flows into the machining area by the multi-hole from the electrode. The bottom edge of the multi-hole electrode was immersed in the special spark oil to allow gas–liquid mixing. Before gas–liquid EDM process, the pressure of nitrogen was adjusted to achieve an effective gas–liquid mixed dielectric condition. Based on a large number of prior experiments,

| Table 1 Chemical component of Ti-6Al-4 V |  |
|---|---|---|---|---|---|---|---|
| Chemical composition | Al | Si | K | Fe | V | Ni | Ti |
| Content/% | 5.8 | 0.152 | 0.0196 | 0.2 | 4.27 | 0.0304 | Rest |
the pressure of nitrogen was chosen as 0.02 MPa. The reason is that too high pressure would lead to discharge in gas, or too small pressure would cause complete discharge in liquid. The sealing ring is connected with the gas supply system to ensure gas tightness during the machining. In order to make nitrogen distributed evenly on the workpiece, spark position shaking on the EDM machine is adopted.

The machining properties of Ti-6Al-4 V alloy in different machining parameters were investigated. Input and output parameters are listed as a block scheme in Table 3. The selection of peak current and pulse duration as input parameters were based on the rationale that literature revealed that these parameters have significant influences for EDM process [13, 14]. The setting of input parameters was based on preliminary study and available low, medium, and high parameters with the actual processing effect, and Table 4 shows the detail of input parameters. Considering the prior experiments and the capabilities of EDM machines, the other parameters remain unchanged with the pulse off time of 20 μs and the supply voltage of 60 V, the polarity is positive, and the experiments are performed for 10 min.

After experimentation, the specimen was cleaned by ultrasonic cleaning machine for 10 min, followed by air drying, then using a scanning electron microscope (SEM; Apreo, FEI Ltd., Hillsboro, OR, USA) to observe surface morphology and using energy dispersive spectroscopy (EDS; Apreo, FEI Ltd., Hillsboro, OR, USA) to analyze elemental composition. Surface roughness (Ra) was measured by the TR200 roughness device (TR200, Time Group Ltd., Shandong, China). To observe the cross section morphology, the samples were mounted, polished, ultrasonically cleaned, and etched by HF: HNO₃: deionized water in the volume ratio of 1:2:7. The micro hardness of the cross section was evaluated by the hardness device (FM800, Future tech Cop., Shanghai, China), with a constant load of 50 gf and a dwell time of 15 s. The X-ray diffraction (XRD; D8 Venture, Bruker Ltd., Madison, WI, USA) was adopted to

| Property       | Dielectric strength (MV/m) | Dielectric constant | Dynamic viscosity (g/m·s) | Thermal conductivity (W/m·K) | Heat capacity (J/g·K) |
|----------------|----------------------------|---------------------|---------------------------|-----------------------------|----------------------|
| Nitrogen       | 2.8                        | 1.0                 | 0.01                      | 0.025                        | 1.04                 |
| Special spark oil | 1.7                      | 1.8                 | 1.64                      | 0.149                        | 2.16                 |

Fig. 1 Multi-hole electrode

Fig. 2 Experimental set-up (a) Experimental schematic; (b) Experimental photograph
analyze the phase of the machined surface. The wear resistance was performed by the wear tester (MMU-10G, Shijin Group Co., Ltd., Jinan, China) under a ball-on-disk linear reciprocating sliding mode, the test standard was carried out in accordance with the ASTM-G133-05(2016) standard, and the parameters were partially modified according to the actual conditions. The material of the ceramic ball (Al₂O₃, diameter 8 mm) was used as the friction counterpart, the tests were conducted for 1000 s at 5 mm/s under a load of 25 N, the single stroke length was 6.0 mm and the oscillating frequency was 5 Hz, all wear tests were applied at room temperature without lubricant. The mass loss of samples was measured by the electronic analytical balance (0.1 mg), the morphologies of worn surfaces morphology were observed by SEM. The wear tests for each sample were carried out for three times to avoid unnecessary error, and the representative results are shown in the work.

3 Results and discussion

3.1 Surface morphology

The surface morphology of machined surface at different parameters for EDM and G-LEDM process is shown in Fig. 3. Comparing the G-LEDMed surface (Fig. 3b, d, f) and the EDMed surface (Fig. 3a, c, e), the G-LEDMed surface has fewer pores than the EDMed surface at the same parameter, this can be attributed to the flow of nitrogen that facilitates the molten materials uniformly distributed on the surface, the pores would be covered by the molten materials, thus the number of pores on the gas–liquid mixed dielectric is reduced. In addition, it can be observed on increasing the processing parameters, the EDMed surface becomes worse, especially in Fig. 3(e), in which large and deep holes with micro cracks distributed on the surface. This may be because the single pulse energy is large at high parameters, and more molten materials are ejected from the molten pool, resulting in deepening of discharge crater and deterioration of surface quality [15]. However, it can be seen that with the enhancement of machining parameters, the G-LEDMed surface has better surface morphology with fewer deep pores and micro cracks, which is quite different from the EDMed surface. This may be because the flow of nitrogen disperses the discharge energy, and the energy per unit area is reduced, which leads to less molten materials that are thrown from the molten pool, thus, the surface morphology is better than the EDMed surface.

The surface morphology of EDM and the G-LEDM process is characterized by the presence of many discharge craters, as shown in Fig. 3, which were marked with circles. The discharge craters are generated due to the successive impacts of discrete electrical discharge. To further analyze the variation of the discharge crater size, five randomly selected discharge craters were chosen for measurement through the metallographic images, and the average value of discharge crater size was determined. Figure 4 illustrates the discharge crater size at different parameters for EDM and the G-LEDM
process, respectively. It is noted that with increasing the discharge current and the pulse duration, the size of the discharge crater of G-LEDMed surface varied from 60.31 to 176.28 μm, whereas the size of discharge crater of EDMed surface increased from 39.97 to 133.75 μm. Xu et al. [12] showed that the size of discharge crater is mainly related to discharge energy. This phenomenon can be explained that the higher discharge current and the extended pulse duration generated more heat to the machined surface, the increasing energy causes the crater size to grow. Regardless of the processing parameter, the size of discharge crater on the G-LEDMed surface is larger than that on the EDMed surface under the same parameter. This may be because nitrogen is involved in the spark discharge, and the liquid
Dielectric mixed with nitrogen has a weaker compression effect than the liquid dielectric [16], thus the discharge channel diameter becomes larger than that of liquid dielectric, which is decreasing the energy density, in this condition, the discharge energy is evenly distributed over a larger area on TC4 machined surface. Therefore, shallower discharge craters with large diameters are formed on the machined surface. Furthermore, there is additional heat except for the heat generated from the discharge energy. The extra heat may come from an exothermic reaction between nitrogen and molten titanium alloy at high temperatures, leading to larger craters. A similar explanation was also put forward by Singh et al. [17].

### 3.2 Surface roughness

Figure 5 displays surface roughness at different parameters for EDM and the G-LEDM process. It is cleared that the surface roughness of both processes is increased corresponding to a rise in the machining parameter, which is attributed to the increase of peak current and pulse duration causes more discharge energy generated, resulting in more molten material thrown out from the molten pool, the surface roughness is rougher. However, compared to the surface roughness of EDM, the gas–liquid mixed EDM process obtains lower surface roughness, which can be reduced up to 28% over that for the EDM process, which is due to the expansion of the discharge channel associated with the addition of nitrogen gas, and the energy density is decreasing [18]. Consequently, the spark energy per unit area of the samples is reducing. Since the shallower and larger craters are distributed on the G-LEDMed surface, as mentioned in Sect. 3.1, the surface quality is improved. Moreover, nitrogen moves randomly in the discharge channel under the flow of spark oil medium, which leads to the distribution of molten materials more even; as a result, the machined surface is smoother.

### 3.3 Cross section morphology

Figure 6 plots the cross section morphology of machined surface at a different parameter. Different regions of each recast layer were randomly selected, and the average of recast layer thickness was determined. Table 5 presents the thickness of the recast layer at different parameters for EDM and G-LEDM process. Figure 6(a), (b) show the cross section morphology of EDMed and G-LEDMed at small parameters. Some cracks and pores could be observed on the EDMed surface, while not on the G-LEDMed surface, and the recast layer of gas–liquid mixed EDM is more continuous than that of EDM. The reason is that nitrogen enters the discharge channel, which disperses the discharge energy and generates a larger range of spark discharge. Therefore, the discharge spot is more uniform, reducing the uneven discharge spot in liquid EDM. Accordingly, the recast layer of G-LEDM is more continuous and consistent. The uniform recast layer is in accordance with the results of Wu et al. [19] despite a quiet difference in the surface modification method (high temperature gas nitriding).

With the increase of machining parameters, the EDMed recast layer (Fig. 6(c)) is more irregular with more deep pores, and the layer thickness obtained here is about 52.976 μm, larger than that of 7.975 μm at small parameter. That is perhaps due to the discharge energy enhances with the boost of peak current and pulse duration, which leads to more materials melting. However, the proportion of molten material that can be flushed away by the dielectric is constant [20]. Thus, more molten materials are
re-solidified on the workpiece surface compared with that of small parameters. The pores are the results of the gas in the molten pool that could not expel during the material solidification process [21], and with the extension of pulse duration, the gas has more time to trap inside the recast layer, forming the deep pores.

As shown in Fig. 6(d), the recast layer is uniform with the absence of pores, and the recast layer thickness here is reaching about 107.441 \( \mu \text{m} \), thicker than that of 52.976 \( \mu \text{m} \) in Fig. 6(c). The same phenomenon happens in the small parameter that the thickness of the gas–liquid mixture is thicker than that of the liquid dielectric. Although the heat on the workpiece can melt the workpiece, the explosive effect induced by the discharge in N2 gas is weaker than that of special oil, in this condition, the explosive force is insufficient to throw the molten material away from the

| Conditions | The recast layer thickness of different regions (\( \mu \text{m} \)) | Average thickness (\( \mu \text{m} \)) |
|------------|---------------------------------------------------------------|----------------------------------|
| Low parameter EDM | 9.52, 3.57, 12.50, 4.17, 7.14, 8.93, 10.71, 7.74, 7.14, 8.33 | 7.975 |
| Low parameter G-LED | 9.52, 7.14, 11.90, 10.12, 7.14, 8.33, 13.10, 12.50, 10.12, 9.52 | 9.939 |
| High parameter EDM | 82.14, 58.33, 59.52, 59.92, 69.05, 53.57, 54.17, 26.19, 40.48, 26.79 | 52.976 |
| High parameter G-LED | 77.98, 92.86, 88.10, 118.45, 123.81, 119.64, 123.21, 122.62, 119.64 | 107.441 |
workpiece surface. Therefore, the thickness of the recast layer is enhanced. In addition, the heat convection of nitrogen takes some of the heat away and has a cooling effect on the solidification process [22]. Hence, the cooling rate of gas–liquid mixed dielectric is faster than that of the pure liquid dielectric, some molten materials re-solidified on the surface before being thrown out. Hence, the recast layer is thicker than that machined in liquid dielectric, which is contrary to the phenomenon studied by Wang et al. [23].

Observing the cross section morphology of the sample obtained in the gas–liquid mixed dielectric (Fig. 6(b), (d)), it is noticed that the bond between recast layer and the matrix is dense. Besides, the microstructure of the recast layer is mainly granular and dendritic, moreover, the particles gradually become fine and dense from the matrix to the machined surface, and transit from dendritic to granular. The similar results have been found by Morton et al. [24]. Different solidification rates at different depths lead to different microstructures. During the G-LEDM process, nitrogen is blown into the machined surface, and the machined surface cools rapidly, forming a dense recast layer. However, with the increase of the depth, the internal temperature of the workpiece is higher, the temperature difference increases, thus the cooling rate is slower than the machined surface. Due to the difference of thermal expansion coefficient of titanium alloy, the volume of the internal workpiece is contracted; hence, the molecular density changes, forming the dendritic structure.

3.4 Surface element analysis

To further explore the cause of different microstructures, two typical samples with different microstructures were chosen for surface element analysis. Figure 7 shows the surface element analysis of EDM and G-LEDM process at the same parameter, respectively. The sampled region is shown in the red box. Different surface morphology has distinct element content. It can be observed that the peak of N element is visible on the gas–liquid mixed EDMed surface, but not on the EDMed surface. The presence of N element
on the gas–liquid mixed machined surface confirmed that the migration of N element from nitrogen to the machined surface, which is ascribed to nitrogen that ionizes under high temperature and high pressure produced by spark discharge, resulting in the deposition of ionized nitrogen on titanium alloy surface. Therefore, the existence of N can be obtained on the G-LEDMed surface, which eventually led to a different microstructure on the machined surface.

3.5 XRD analysis

To elucidate the phase composition over the machined surface, the G-LEDMed surface obtained under large parameters was analyzed by XRD as shown in Fig. 8. Results show that TiN, Ti, and Al phases are present on the workpiece surface. The formation of TiN hard phase is owing to the instantaneous energy of spark discharge melts the titanium alloy and forms a molten pool, at the same time, nitrogen decomposes into nitrogen atoms at high temperature, and even ionizes into nitrogen ions. The molten titanium reacts with nitrogen to form TiN hard phase. The formation of TiN confirms that the element N in Sect. 3.4 exists in the form of compound. The Ti and Al phases come from the remaining molten titanium after the nitriding reaction.

3.6 Micro hardness

The micro hardness of the recast layer plays an important part in wear resistance. Figure 9 depicts the distribution curve of micro hardness on the cross section of surfaces machined by EDM and G-LEDM process at high parameter,
respectively. The micro hardness of G-LEDM process varies between 1329.5 and 314 HV, while that of EDM ranges between 801.6 and 314 HV, which reveals that the micro hardness of G-LEDM process is almost 65.9% higher than that of EDM process, which is more than 3 times that of the matrix material. The improvement of micro hardness is owing to the formation of TiN hard phase on the sample surface, which was confirmed by Kumar et al. [25] and Escalona et al. [26] that TiN ceramic layer has a high hardness. The maximum micro hardness of 1329.5 HV was observed on the top of the machined surface. With the increase of the depth, the micro hardness decreases gradually until it reaches the matrix hardness (314 HV). This variation of micro hardness corresponds to the analysis of cross section morphology as mentioned in Sect. 3.3 that the thickness of TiN recast layer of gas–liquid EDM is thicker. The micro hardness of the location below the surface 20 μm is 1001.9 HV, and the micro hardness at 60 μm away from the surface is still higher than 679 HV, while at the same distance, the micro hardness of EDM process is 314 HV, which is the same as the matrix hardness.

### 3.7 Wear resistance

The friction coefficients versus test time for G-LEDM and EDM process are shown in Fig. 10. The friction coefficients of both processes increased quickly at the beginning of the wear test, ensuing in a trace on the machined surface, then the friction coefficients for G-LEDMed surface and EDMed surface increased slowly in an oscillating manner. It is worth noting that the fluctuation range of G-LEDMed surface is lower than that of EDMed surface. The relatively low friction coefficient is attributed to TiN hard layer formed on the surface, which has better wear resistance [27, 28]. This is consistent with the enhancement of micro hardness discussed in Sect. 3.5.

Figure 11 represents the comparison of mass loss with test time for the G-LEDM and EDM process. As shown in Fig. 11, the accumulated mass loss of the G-LEDMed surface was about 0.55 mg, while the mass loss of EDMed surface was about 1.41 mg. It can be seen that the mass loss of G-LEDM process is less than that of EDM process, which implies that the gas–liquid EDM process obtains better wear resistance.

Figure 12 illustrates the typical surface morphology of G-LEDM and EDM process after the wear test. As shown in Fig. 12, the EDMed surface has deep obvious furrows and wear debris on the wear trace, while the wear trace on the G-LEDMed surface is relatively shallower under the same parameters. It can be deduced that the G-LEDM process obtains better wear resistance. The main reason for the better resistance is due to the formation of TiN hard layer on the machined surface, which further enhances the micro hardness of the machined surface.

### 4 Conclusions

In conclusion, the machining properties of Ti-6Al-4 V alloy by G-LEDM process were investigated in nitrogen-liquid dielectric. The main conclusions can be drawn:

1. The G-LEDM process obtains better surface performance with fewer pores and micro cracks as compared with EDM process. With the increase of machining parameter, the discharge craters of G-LEDMed surface varies from 60.31 to 176.28 μm, which are larger than that of EDMed surface.
(2) The surface roughness of the G-LEDM process is lower than that of EDM process which can be reduced by about 28% due to shallower and larger discharge craters formed on G-LEDMed surface, generating smoother surface.

(3) The recast layer of G-LEDM process is more continuous and thicker than that of EDMed surface. The bond of G-LEDMed surface between recast layer and the matrix is dense and its microstructure is mainly granular and dendritic.

(4) The N element migrated from nitrogen gas to the sample surface and XRD analysis reveals that the hard phase of TiN is formed on the gas–liquid mixed EDMed surface attributed to a chemical reaction between titanium alloy and nitrogen gas at elevated temperature.

(5) The average micro hardness of G-LEDM process increases from 315 (the matrix) to 1329.5 HV, which is improved by almost 65.9% as compared to that of EDM process. With the increase of depth from the surface, the micro hardness decreases gradually until it reaches the matrix hardness.

(6) The Wear test shows that G-LEDM process is superior to the EDM process at the same parameter, thus the average friction coefficient in the stable wear stage decreased from 0.208 to 0.171 and the mass loss is less than that of the EDM process.

(7) The G-LEDM process serves as a surface modification method that effectively improves the surface properties and saves the cost, in contrast to other methods.

Author contribution Wei Zhang: experiments, writing the original draft, result analysis. Li Li: resources, editing, data curation, project administration. Ning Wang: methodology, investigation, experiments. Jianjing Meng: resources, supervision. Jianhua Ren: conceptualization, resources.

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Declarations

Ethics approval and consent to participate This work has not been published elsewhere.

Conflict of interest The authors declare no competing interests.

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