Study of morphological and mechanical features of multinuclear and mononuclear SW480 cells by atomic force microscopy

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Abstract

This article studies the morphological and mechanical features of multinuclear and mononuclear SW480 colon cancer cells by atomic force microscopy to understand their drug-resistance. The SW480 cells were incubated with the fullerol concentrations of 1 mg/ml and 2 mg/ml. Morphological and mechanical features including the height, length, width, roughness, adhesion force and Young’s modulus of three multinuclear cell groups and three mononuclear cell groups were imaged and analyzed. It was observed that the features of multinuclear cancer cells and mononuclear cancer cells were significantly different after the treatment with fullerol. The experiment results indicated that the mononuclear SW480 cells were more sensitive to fullerol than the multinuclear SW480 cells, and the multinuclear SW480 cells exhibited a stronger drug-resistance than the mononuclear SW480 cells. This work provides a guideline for the treatments of multinuclear and mononuclear cancer cells with drugs.

KEYWORDS

atomic force microscope, mechanical features, mononuclear cells, morphological features, multinuclear cells

1 | INTRODUCTION

A tumor cell, often contains more nuclei (Lu & Kang, 2009; Sheehy, Wakonig-Vaartaja, Winn, & Clarkson, 1974; Zhu & Friedland, 2006). The fusion of plasmodia (Beno et al., 2005; Ming, Dong, Zhong, Grevelding, & Jiang, 2006; Walter, Hoffmann, Ebeling, Haas, & Marwan, 2013), closed mitosis (Guffei et al., 2010; S. Kim et al., 2005) and cell division (Cool et al., 1992; Kuroda & Furuyama, 1963) can lead to the coexistence of different nuclei and formation of multinuclear cells (Papadimitriou, Sforsina, & Papaelias, 1973). Studies have shown that multinuclear cells commonly exist in tumors and they are a key character for the diagnosis of cancer (Knecht et al., 2009; Knecht, Sawan, Lichtensztejn, Lichtensztejn, & Mai, 2010; W. Zhang, Lin, Ramoth, Fan, & Fidler, 2011).
Cancer treatment has been an important issue and great efforts have been devoted to the diagnosis and therapy of cancers (Babahosseini, Carmichael, Storbl, Mahmoodi, & Agah, 2015; Byun et al., 2013). Because of the nanoscale resolution of atomic force microscope (AFM) in the imaging, manipulation and measurement of biological objects and structures (Lazar et al., 2013; Nawaz et al., 2012; Sokolov, 2007; Xu et al., 2012; Zhang et al., 2013; Zhang, Aslan, Besenbacher, & Dong, 2014), it has been used to investigate morphological and mechanical features of living cells (Heu, Berquand, Elie-Caille, & Nicod, 2012; Li, Mansoor, Tan, & Lim, 2006; Liu, Song, Qu, Wang, & Wang, 2015; Sikora & Iwan, 2012). Thus, AFM can be a proper tool for the manipulation and measurement of cancer cells. Studies about the changes of morphological and mechanical features of cancer cells after the treatment with anti-cancer drugs were taken. Gaspar et al. (Gaspar, Freire, Pacheco, Barata, & Castanho, 2015) studied the effect of HNP-1 on PC-3 cells and MOLT-4 cells by AFM, and the results showed that the height decrease was caused by the HNP-1 treatment. The roughness of the cell membrane is related the cell motility, and it can be used to characterize the state of cells (Antonio, Lasalvia, Perna, & Capozzi, 2012; Girasole et al., 2007). Kim et al. (Kim et al., 2012) found by AFM that the roughness of HeLa cells was increased significantly after the treatment with paclitaxel. Pelillo et al. (Pelillo et al., 2016) investigated the adhesion and morphology features of colorectal cancer cells (HCT-116) to study their metastatic behaviors affected by ruthenium drug NAMI-A. Hayashi et al. (Hayashi & Iwata, 2015) and Ansardamavandi et al. (Ansardamavandi, Tafazzoli-Shapoori, Omidvar, & Jahanzad, 2016) evaluated the stiffness changes of cancer cells to understand the pathophysiology. Efremov et al. (Efremov et al., 2014) characterized the cell area, focal adhesion and Young’s modulus distributions of tumor cells and normal cells with AFM to study their transformational changes. Hence, morphology and mechanics are significant features for the investigation of cancer cells (Cio & Gautrot, 2016; Wirtz, Konstantopoulos, & Earnshaw, 2011). However, little work has been carried out to investigate the difference of drug-resistance between multinuclear cancer cells and mononuclear cancer cells after the treatment with anti-cancer drugs.

In this work, fullerol \( \text{C}_{60} \text{(OH)} \text{x} \) was used as an anticancer drug to treat SW480 colon cancer cells. The morphological and mechanical features of SW480 colon cancer cells, such as the height, length, width, roughness, adhesion force and Young’s modulus, were investigated after the treatment with fullerol to understand their drug-resistance. Different fullerol concentrations of 1 and 2 mg/ml were used in the experiment. The details are described in the following sections.

## 2 MATERIALS AND METHODS

### 2.1 Culture of cells

Colon cancer cells SW480 (CBTCCCAS, Shanghai, China) were maintained under 5% CO₂ at 37°C. The cells were attached to 0.01 mg/ml Poly-L-Lysine (HyClone) treated glass bottom culture dishes (18 mm × 18 mm) and were cultured in the RPMI-1640 media (HyClone) including 10% fetal bovine serum (HyClone).

Fullerenol \( \text{C}_{60} \text{(OH)} \text{x} \) (Baena, Gallego, & Valcárcel, 2002; Gao et al., 2011; Rade, Natasa, Biljana, Aleksandar, & Borut, 2008) has been used as antioxidants, anticancer, and antimicrobial drugs (Chaudhuri, Paraskar, Soni, Mashelkar, & Sengupta, 2009; Grebowsk, Krokosz, & Puchala, 2013; Injac et al., 2008; Torres et al., 2010; Çavas, Cinkucle, Vatan, & Yilmaz, 2014) due to the unique structures and properties. In this work, the fullerol (Hengqiu Tech, China) concentrations of 1 and 2 mg/ml were used to treat SW480 cells for 24 hr, 48 hr, and 72 hr before the measurement experiment.

### 2.2 Sample preparation

To study the morphological features of cells by AFM, cells were immersed in 2.5% gluteraldehyde for 15 min. The samples were then rinsed three times with phosphate buffer saline (PBS) and naturally dried up at the room temperature and humidity. The prepared samples were stored at 4°C in the dark.

To investigate the mechanical features of living cells by AFM, the cell culture glass slides were washed three times by the PBS to sweep away the suspend cells, and then immersed in RPMI-1640 media to keep the living environment. All steps were taken in a super-clean bench.

### 2.3 AFM

An Agilent 5500 AFM system was used for the measurement of morphology features (height, length, width and roughness) of SW480 cells in the air, at a temperature of 23°C and a humidity of 50%. The tapping mode was used for imaging, the scanning rang was varied from 20 μm × 20 μm to 90 μm × 90 μm, and the scanning speed was 0.2 line/s. The tip radius was 10 nm. The thickness of cantilever was 4 μm, and the width and length were 30 μm and 125 μm, respectively. The normal spring constant of cantilever was 40 N/m, and the resonance frequency was 300 kHz (Tap300, BudgetSensors). To analyze the changes of height, length, width and roughness of mononuclear cells and multinuclear cells after the treatment with fullerol, and study their drug-resistance, 10–28 mononuclear cells and multinuclear cells were selected from each groups and measured by AFM. The height, length, width and roughness features of each group of cells were obtained by image processing software “Pico Image Expert 6.2” from Agilent (USA).

A JPK AFM system (NanoWizard®III, Germany) was used for the measurement of the mechanical features (adhesion force and Young’s modulus) of SW480 living cells in the RPMI-1640 medium. The quantitative imaging (QI) mode was applied to obtain the force mapping images of the living cells and the loading speed was 200 μm/s. The scan rate was in the range of 0.5–0.8 Hz. The probe used in the experiments was MLCT (BRUKER). The tip radius was 20 nm. The thickness of cantilever was 0.55 μm, and the width and length were 20 and 225 μm, respectively. The resonance frequency of cantilever was 15 kHz and the spring constant was 0.03 N/m. For measuring of the adhesion force, at least 10 cells were detected in each of the groups and 15 force curves were recorded for each cell. The AFM force-displacement
curves were obtained from measuring the nucleus areas of cells (Cao, Sui, & Sun, 2013). Five cells were studied in each of the groups and 100 measurements were made for each cell to investigate the Young’s moduli. The distributions of Young’s moduli were obtained by Gaussian curve fitting. The probing positions were the nucleus areas of cells. The adhesion forces and Young’s moduli were obtained by image processing software “JPKSPM Data Processing” from JPK Instruments AG (Germany).

2.4 | MTT assay

SW480 cells were planted \((2 \times 10^4)\) in a 96-well plate and incubated at \(37^\circ C\) for 48 hr. They were then treated with 1 mg/ml and 2 mg/ml of fullerenol and incubated for another 24 hr, 48 hr, and 72 hr. After that, 20 \(\mu\)l of 5 mg/ml dimethyl thiazolyltetrazolium bromide (MTT) was added to each well. After the incubation at \(37^\circ C\) for 4 hr, all media were aspirated and each well was treated with the 150 \(\mu\)l DMSO solution. Finally, the cell viability was measured using the microplate reader (Sanco, China) at an absorbance wavelength of 570 nm. Each treatment was repeated three times.

2.5 | Statistical analysis

Statistical analysis was performed by SPSS 18.0 software. One-way analysis of variance (ANOVA) was used to evaluate the data distribution. Data were shown as Mean \(\pm\) SD. The value of \(p < 0.05\) was considered significant and \(p < .01\) was considered highly significant.

3 | RESULTS AND DISCUSSIONS

Figure 1a–c show the optical images of SW480 cells of the control group and the two groups incubated with the fullerenol concentrations of 1 and 2 mg/ml for 48 hr. The MTT assay was used to evaluate the growth inhibitory effects of fullerenol and the results of cell viability distributions of SW480 cells were treated with two concentrations of fullerenol for 24 hr, 48 hr, and 72 hr as shown in Figure 1d. It can be observed clearly from Figure 1a–c that with the increase of the concentration of fullerenol, the number and the length of cells are declined. From Figure 1d, it can be seen that the viabilities of SW480 cells after the treatment with 2 mg/ml fullerenol are smaller than those of the cells treated with 1 mg/ml fullerenol.

It is known that the morphology property change is a good way to evaluate the drug-resistance of cancer cells (Cai, Gao, Cai, Wu, & Deng, 2009). In this work, morphological images of SW480 cells were obtained by AFM. Figure 2a–c show the AFM morphological images of control group, 1 and 2 mg/ml fullerenol treatment for 48 hr groups of SW480 cells. It has been found that the shapes of SW480 cells untreated with fullerenol are normal, but the shapes of cells treated with the fullerenol have been changed. The color bar indicates the height of the cells. Figure 2d is the 3D structure of mononuclear SW480 cell. Figure 2e,f show the 3D structures of multinuclear cells. It can be clearly seen that there are two nuclei in Figure 2e and three nuclei in Figure 2f. From the 3D structures of cells, many nano/micro scale characters of cells can be obtained (Labernadie, Thibault, Vieu, Mariodonne-Parini, & Charrière, 2010).
Figure 3 shows the distributions of height, length, width and roughness of mononuclear and multinuclear SW480 cells in the control group and the two groups treated with fullerenol for 48 hr. Figure 3a is the mononuclear SW480 cell and (B) is the two-nuclear SW480 cell. From the optical images, the number of nuclei can be seen clearly and they are labeled by arrows. The height distributions of the mononuclear
and multinuclear SW480 cells are shown in Figure 3c. The height of mononuclear cells in the control group is 2.16 ± 0.29 μm, and after 2 mg/ml fullerenol treatment it is increased to 3.32 ± 0.15 μm. The height of multinuclear cells in the control group is 1.74 ± 0.20 μm and it is changed to 2.47 ± 0.38 μm after 2 mg/ml fullerenol treatment. The width distributions of mononuclear and multinuclear SW480 cells are shown in Figure 3d. The length of mononuclear cells in the control group is 41.78 ± 1.90 μm, and after 2 mg/ml fullerenol treatment it is decreased to 10.13 ± 1.02 μm. The height of multinuclear cells in the control group is 46.82 ± 3.68 μm and it is changed to 30.32 ± 6.36 μm after 2 mg/ml fullerenol treatment. The width distributions of mononuclear and multinuclear SW480 cells are shown in Figure 3e. The width of mononuclear cells untreated with fullerenol is 10.36 ± 1.39 μm, and after 2 mg/ml fullerenol treatment it is decreased to 8.31 ± 1.03 μm. For the multinuclear SW480 cells, the width in the control group is 10.78 ± 2.64 μm, and after 2 mg/ml fullerenol treatment it is reduced to 9.27 ± 1.03 μm. The roughness distributions of mononuclear and multinuclear SW480 cells are shown in Figure 3f. The roughness of mononuclear cells untreated with fullerenol is 0.42 ± 0.10 μm, and after 2 mg/ml fullerenol treatment it is increased to 0.74 ± 0.07 μm. For the multinuclear SW480 cells, the roughness in the control group is 0.30 ± 0.02 μm, and after 2 mg/ml fullerenol treatment it is increased to 0.49 ± 0.15 μm. p < 0.05.

It can been seen from the AFM measurement results that the morphological features of height, length, width and roughness between the multinuclear SW480 cells and mononuclear SW480 cells are significantly different after the treatment with fullerenol. The changes of mononuclear SW480 cells are larger than the multinuclear cells. It can be concluded that the drug-resistance of multinuclear cells are stronger than that of mononuclear SW480 cells.

The mechanical properties such as the adhesion force and elasticity of cells can be used to reflect the cell viability (Cai et al., 2009; Jin et al., 2011). In this work, the adhesion force and Young’s modulus of multinuclear and mononuclear cancer cells were measured to investigate their drug-resistance after the fullerenol treatment. The Hooke’s law and Hertz model were used to measure the distributions of adhesion force and Young’s modulus, respectively (Butt, Cappella, & Kappl, 2005; Zhao, Srinivasan, Burgess, & Huey, 2011). The adhesion force of tip-cell can be calculated by the deflection of the cantilever, and it can be expressed by the Hooke’s law

\[ F = k \times \Delta L \quad (1) \]

where \( k \) is the spring constant of the cantilever \((k = 0.03 \text{ N/m})\). \( \Delta L \) is the deflection of the cantilever. The original Hertz theory is an approximation for the contact of the very shallow indentation of two spheres in contact. For a pyramidal tip, the Hertz model can be modified as (Rico et al., 2005)

\[ F = \frac{1}{\sqrt{2}} \frac{E}{1-v^2} \delta^2 \tan \alpha \quad (2) \]

where \( F \) is the force, \( E \) is the Young’s modulus of the sample, \( v \) is the Poisson’s ratio \((v = 0.5)\), \( \delta \) is the indentation depth calculated from the force-displacement curve. In this work, \( \delta \) is in the range of 350-600 nm. \( \alpha \) is the angle of the pyramidal tip \((\alpha = 15^\circ)\).

Figure 4 shows the adhesion force images of mononuclear and multinuclear SW480 cells after the treatment with 1 mg/ml fullerenol for 48 hr. The color bar indicates the adhesion force of the cells. It can be seen that the adhesion forces between mononuclear cells and multinuclear cells are different even though they are both SW480 cells. The optical microscope images in Figure 4b,d show that the multinuclear cells are normal but the mononuclear cells are in apoptosis.

Figure 5 shows the force-displacement curves of living SW480 cells after the treatment with fullerenol for 48 hr. Figure 5b is the enlarged image of the square area in Figure 5a. The distance between the lowest position and the base line is the adhesion force of tip-cell. It can be seen that the adhesion forces between the mononuclear and the multinuclear SW480 cells are different. It can be found that the adhesion forces are declined with the increase of the concentration of fullerenol and the adhesion forces of multinuclear cells are larger than those of mononuclear cells after the treatment with fullerenol with the same concentration.

Figure 6 shows the adhesion force distributions of multinuclear and mononuclear SW480 cells in the control group and the two groups treated with the two concentrations of fullerenol for 24 hr, 48 hr, and 72 hr. For the control groups untreated with fullerenol, the adhesion forces of mononuclear cells and multinuclear cells after incubation for 24 hr are 49.4 ± 2.5 pN and 50.3 ± 2.4 pN, respectively. The values are almost the same. After incubation for 48 hr, the adhesion force of mononuclear cells is 44.9 ± 4.2 pN and the adhesion force of multinuclear cells is 49.0 ± 2.4 pN. After 72 hr incubation, the adhesion force of mononuclear cells is 42.7 ± 3.2 pN and the adhesion force of multinuclear cells is 47.6 ± 1.9 pN. It can be seen that the adhesion force differences of multinuclear and mononuclear cells untreated with fullerenol are insignificant in the same time periods.

Figure 6a shows the SW480 cells treated with fullerenol for 24 hr, the adhesion forces of mononuclear cells and multinuclear cells after treatment with 1 mg/ml of fullerenol are 42.2 ± 2.9 pN and 48.7 ± 1.5 pN, respectively. For the SW480 cells treated with 2 mg/ml of fullerenol for 24 hr, the adhesion forces of mononuclear cells and multinuclear cells are 33.9 ± 3.5 pN and 48.5 ± 3.5 pN. Figure 6b presents the SW480 cells treated with fullerenol for 48 hr, the adhesion forces of mononuclear cells and multinuclear cells treated with 1 mg/ml of fullerenol are 30.6 ± 3.6 pN and 43.7 ± 2.0 pN. For the SW480 cells treated with 2 mg/ml of fullerenol for 48 hr, the adhesion forces of mononuclear cells and multinuclear cells are 29.7 ± 4.0 pN and 42.4 ± 1.1 pN. Figure 6c shows the SW480 cells treated with fullerenol for 72 hr, the adhesion forces of mononuclear cells and multinuclear cells treated with 1 mg/ml of fullerenol are 28.5 ± 3.6 pN and 39.4 ± 3.0 pN. For the SW480 cells treated with 2 mg/ml of fullerenol for 72 hr, the adhesion forces of mononuclear cells and multinuclear cells are 26.6 ± 3.0 pN and 36.3 ± 3.6 pN, respectively.

Significantly higher adhesion forces of multinuclear cells are observed than the mononuclear cells after the treatment with 1 or 2 mg/ml fullerenol for the same time periods. It can be concluded that after the treatment with fullerenol, the multinuclear SW480 cancer cells exhibit significant drug-resistance than the mononuclear cells.
Figure 7 shows the distributions of Young’s moduli from multinuclear and mononuclear SW480 cancer cells after treatment with fullerenol for 24 hr, 48 hr, and 72 hr. The Young’s moduli are calculated from 5 cells in each of the groups and 100 measurements were made for each cell, as shown in Table 1. \( p < 0.01 \), when compared with the control group.

Figure 7a shows the distributions of Young’s modulus of SW480 cells exposed to fullerenol for 24 hr. For the multinuclear cells, the Young’s moduli are distributed between 150 and 400 Pa. The Mean ± SD modulus of the control group is 295.0 ± 112.1 Pa, and those of the SW480 cells treated with 1 mg/ml and 2 mg/ml fullerenol are 297.7 ± 104.3 Pa and 302.5 ± 109.8 Pa, respectively. For the mononuclear cells, the Young’s moduli of control group and the group treated with 1 mg/ml fullerenol SW480 cells are distributed between 150 and 400 Pa, and there are insignificant difference between their Mean ± SD moduli.

**Figure 4** Adhesion force images of mononuclear and multinuclear SW480 cells after the treatment with 1 mg/ml fullerenol for 48 hr. (a) is the adhesion force image of a mononuclear SW480 cell. The image resolution is 64 x 64 pixels. (c) is the adhesion force image of a multinuclear SW480 cell. The image resolution is 64 x 45 pixels. (b) and (d) are the detected cells captured by optical microscope [Color figure can be viewed at wileyonlinelibrary.com]

**Figure 5** (a) shows the force-displacement curves of living SW480 cells in culture. (b) shows the enlarged image of the square area of (a) [Color figure can be viewed at wileyonlinelibrary.com]
311.8 ± 142.3 Pa and 310.3 ± 113.8 Pa, respectively. The Young’s moduli of mononuclear SW480 cells treated with 2 mg/ml fullerenol are distributed between 200 and 500 Pa and the Mean ± SD modulus is 357.8 ± 111.8 Pa. It can be observed that after 24 hr treatment with fullerenol, the Young’s moduli distributions of multinuclear cells and their Mean ± SD values were not significantly changed. However, there is a significant difference in Young’s moduli of the mononuclear cells treated with 2 mg/ml fullerenol group.

Figure 7b shows the distributions of Young’s moduli of SW480 cells exposed to the fullerenol for 48h. The Young’s moduli of the multinuclear cells and mononuclear cells of control groups are distributed

<table>
<thead>
<tr>
<th>Group</th>
<th>Control Group</th>
<th>1 mg/ml</th>
<th>2 mg/ml</th>
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</thead>
<tbody>
<tr>
<td>24 hr</td>
<td>Multi</td>
<td>295.0 ± 112.1</td>
<td>297.7 ± 104.3</td>
</tr>
<tr>
<td></td>
<td>Mono</td>
<td>311.8 ± 142.3</td>
<td>310.3 ± 113.8</td>
</tr>
<tr>
<td>48 hr</td>
<td>Multi</td>
<td>375.8 ± 93.6</td>
<td>528.4 ± 130.0</td>
</tr>
<tr>
<td></td>
<td>Mono</td>
<td>395.9 ± 113.5</td>
<td>538.5 ± 137.1</td>
</tr>
<tr>
<td>72 hr</td>
<td>Multi</td>
<td>202.5 ± 80.2</td>
<td>301.1 ± 101.8</td>
</tr>
<tr>
<td></td>
<td>Mono</td>
<td>235.5 ± 83.0</td>
<td>316.8 ± 152.2</td>
</tr>
</tbody>
</table>
between 250 and 500 Pa and their Mean ± SD moduli are 375.8 ± 93.6 Pa and 395.9 ± 113.5 Pa, respectively. The Young’s moduli of the multinuclear cells treated with 1 mg/ml and 2 mg/ml fullerene are distributed between 350 and 650 Pa and their Mean ± SD values are 528.4 ± 130.0 Pa and 536.3 ± 125.1 Pa, respectively. The Young’s moduli among the groups of multinuclear cells treated with fullerene showed a small variation in their distributions and Mean ± SD values. For mononuclear cells, the Young’s moduli of the SW480 cells treated with 1 mg/ml fullerene are distributed between 350 and 650 Pa and the Mean ± SD value is 538.5 ± 137.1 Pa. The Young’s moduli of the SW480 cells after 2 mg/ml fullerene treatment are distributed between 500 and 850 Pa and the Mean ± SD value is significantly increased to 724.7 ± 207.1 Pa. It can be stated that the Young’s moduli of the mononuclear cells are significantly different from the multinuclear cells groups.

Figure 7c shows the distributions of Young’s moduli of SW480 cells treated with fullerene for 72 hr. The Young’s moduli of the control group of the multinuclear cells and mononuclear cells are distributed between 100 and 350 Pa, and their Mean ± SD values are 202.5 ± 80.2 Pa and 235.5 ± 83.0 Pa, respectively. For the groups treated with 1 mg/ml fullerene, the Young’s moduli of multinuclear cells and mononuclear cells are distributed between 150 and 400 Pa, and their Mean ± SD values are 301.1 ± 101.8 Pa and 316.8 ± 152.2 Pa, respectively. For the groups treated with 2 mg/ml fullerene, the Young’s moduli of multinuclear cells and mononuclear cells are distributed between 150–450 Pa and 150–400 Pa, respectively and the Mean ± SD value increased from 302.0 ± 95.8 Pa to 377.2 ± 226.5. It can be observed that after the treatment with fullerene, there is a significant change of the Young’s moduli of multinuclear cells groups.

Based on these results, it can be concluded that there are significant differences in Young’s moduli of multinuclear cells compared with the mononuclear cells after treatment with fullerene, which is responsible for the variation in their drug-resistance. Furthermore, the Young’s moduli of mononuclear cells are significantly higher than those of multinuclear cells, and they were increased with the increase of the fullerene concentration. However, the Young’s moduli of multinuclear cells showed an insignificant change.

Fullerenol influenced the conformation and function of membranes of cells and deformed the protein in the binding residues (Grebowksi et al., 2013; Qiao, Roberts, Mount, Klaine, & Ke, 2007). Thus, the skeleton and structure of cells were changed (Rungaldier, Oberwagner, Salzer, Csaszar, & Prohaska, 2013) and led to the alterations of mechanical properties (Ansardamavandi et al., 2016).

4 | CONCLUSION

The work reported in this article shows that there are significant differences in the morphological and mechanical features between the mononuclear and multinuclear SW480 cells after the treatment with fullerene. The distributions of the height, length, width and roughness of the multinuclear SW480 cells untreated with fullernol and treated with two concentrations of fullerenol are similar, but for the mononuclear SW480 cells, their distributions are clearly different. The adhesion force of mononuclear SW480 cells is significantly less than that of the multinuclear cells after the treatment with fullerenol for the same time period. The variation of Young’s modulus of mononuclear SW480 cells is significantly larger than the multinuclear SW480 cells after exposure to the fullerenol for the same time period. The AFM results indicated that the mononuclear SW480 cells were more sensitive to fullerenol than the multinuclear SW480 cells, and the multinuclear SW480 cells exhibited a stronger drug-resistance than the mononuclear SW480 cells. This work provides a guideline for the treatments of multinuclear and mononuclear cancer cells with drugs.

ACKNOWLEDGMENTS

This work was supported by EU FP7 (BioRA No.612641), China-EU H2020 (FabSurfWAR Nos.2016YFE0112100 and 644971), EU H2020 (MNR4Cell No.734174), International Science and Technology Cooperation Program of China (No.2012DFA11070), and Jilin Provincial Science and Technology Program (Nos.20140414009GH, 20140622009JC and 20160623002TC).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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