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Aspirin and ibuprofen, in bulk and nanoforms: effects on DNA damage in peripheral lymphocytes from breast cancer patients and healthy individuals

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Keywords: DNA damage; comet assay; lymphocytes; nanoparticles; aspirin; ibuprofen; breast cancer.

Abbreviations

Abstract

Regular use of non-steroidal anti-inflammatory drugs (NSAIDs) may be protective against tumours, including breast cancer. We have studied the effects of ibuprofen and aspirin on DNA damage in lymphocytes obtained from breast cancer patients and healthy female controls. Both nanoparticle (NPs) and bulk formulations were used in the comet and micronucleus (MN) assays. Non-toxic doses (250 ng/ml ibuprofen; 500 ng/ml aspirin) were tested. Aspirin, both bulk and nano formulations, significantly reduced DNA damage measured with the comet and micronucleus assays; the nano formulation was more effective. Ibuprofen was not effective in the comet assay but showed a significant reduction in MN frequency, with the nano formulation being more effective. NPs may have better penetration through the nuclear membrane relative to the bulk formulation. NSAIDs such as aspirin and ibuprofen may have a promising role in cancer prevention and treatment.
1. Introduction

Breast cancer (BC) is the most common cancer affecting females worldwide [1]. BC is more common in developed countries compared to developing countries. Overall survival from BC is increasing but remains poorer in developing countries [1, 2]. Factors in developing nations may include adaptation to Western life-styles; less BC screening; and poorer health-care [1]. BC arises from genetic and epigenetic alterations in mammary cells [3, 4].

The effects of NSAID (ibuprofen, aspirin) use on the incidence of malignancies, including the most prevalent types (lung, prostate, colon, and breast cancers) have been studied [5, 6]. NSAID intake appears to reduce cancer risk. Daily use of NSAIDs, usually aspirin, was associated with risk reductions of 39% (BC), 63% (colon cancer), and 39% (prostate cancer). After 5 y use, NSAIDs impact became apparent, and the effect increased with duration of use [6]. Researchers have emphasized the role of NSAIDs as inhibitors of the cyclooxygenase enzymes COX-1 and COX-2, since inflammation is believed to play a role in BC.

The use of aspirin for prevention of BC is a relatively new subject of study [7]. Protection against BC was observed in some patients who regularly took aspirin, such as patients with cardiac disease. The reduction of BC incidence was linked to inhibition of COX-1 and COX-2, with the former enzyme being inhibited more strongly. COX inhibition blocks production of prostaglandin H2 from its precursor, arachidonic acid, in turn blocking production of other of prostaglandins [7, 8]. Inhibition of prostaglandin production inhibits their physiological roles, such as promotion of cell growth and angiogenesis, contributing to the antitumour effect of NSAIDs. Aspirin also stimulates the AMP-activated protein kinase (AMPK) signalling pathway, thereby inhibiting cancer cell growth.
Prostaglandin E2 can increase expression of aromatase, which is responsible for the biosynthesis of oestrogen. Thus aspirin may indirectly inhibit oestrogen production and associated BC growth. Nevertheless, caution should be exercised in the use of aspirin as a single agent for BC chemoprevention, due to limited available results on its protective action [7, 8].

Harris et al (1999) compared the effects of certain NSAIDs, including ibuprofen, on BC patients. Regular ibuprofen use was associated with reduction of the BC rate by about half, and it was suggested that the drug might be useful in BC prevention [9, 10].

We have investigated the effects of aspirin and ibuprofen on genotoxicity, using lymphocytes obtained from BC patients and healthy female controls. Two different particle sizes were compared: nanoparticles (NPs) and bulk sizes. The comet assay [11-14] and micronucleus (MN) genotoxicity assays [15, 16] were used. Lymphocytes were selected for this study because they may reflect DNA damage induced by both endogenous and exogenous genotoxins, whether chemical or physical agents [17, 18].

The comet assay (single-cell gel electrophoresis assay) can measure DNA damage [11, 19]. It is a highly sensitive method for detection of DNA cross-links and may be applied to any eukaryotic cell [20, 21]. The cytokinesis block micronucleus assay (CBMN) is the preferred method for use with human lymphocytes, since it is restricted to divided binucleate cells. MN are remnants of centric chromosome fragments or entire chromosomes. This fragment nucleus is not incorporated in the daughter nucleus [15, 16]. The CBMN is commonly used to track DNA damage in human lymphocytes [15].
2.0 Material and Methods

2.1. Blood sample collection

Whole blood was collected by venipuncture after receiving informed consent from healthy female volunteers and BC patients. The BC samples were provided by the Ethical Tissue Bank using licence 12191. Blood was collected in labelled lithium heparin-coated tubes. Ethical approval was granted by the University of Bradford’s Sub-Committee for Ethics in Research involving Human Subjects (Reference no.: 0405/8). Control samples were also taken under IRAS/NRES application 12/YH/0464. The Research Support and Governance Office Bradford Teaching Hospital NHS Foundation granted the Re DA number: 1202. Samples were diluted 1:1 with RPMI-1640 medium and then 10% DMSO was added. The diluted blood samples were divided and transferred to labelled Eppendorf® tubes, which were tightly closed and stored at -80°C. However, blood samples were used freshly in the MN assay. The characteristics of the samples are shown in Tables 1a and b.
<table>
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<th>Smoking history</th>
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</tr>
<tr>
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<td>No</td>
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<td>4922</td>
<td>53</td>
<td>Caucasian</td>
<td>16 10/d-32y</td>
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## Table 1b Breast cancer patient characteristics.

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<td>10/d-2y</td>
<td>Ovarian cancer</td>
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<td>BC</td>
<td>No</td>
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</table>
2.2. Chemicals

The chemicals used were: aspirin (CAS 50-78-2) Sigma Gillingham, Dorset UK, cytochalasin-B (CAS. 14930-96-2) Sigma-Aldrich Gillingham, Dorset UK, ethanol (CAS 64-17-5) Sigma Gillingham, Dorset UK, ethidium bromide (CAS 1239-45-8) Sigma Gillingham, Dorset UK, hydrogen peroxide (CAS 7722-84-1) Sigma UK, mitomycin C (CAS 50-07-7) Sigma-Aldrich Gillingham, Dorset UK, ethylenediamine tetraacetic acid, disodium dihydrate (Na 2 EDTA·2H 2 O) (CAS 6381-92-6) Sigma Gillingham, Dorset UK, NaCl (CAS 7647-14-5) Sigma Gillingham, Dorset UK, and phosphate-buffered saline (PBS) Sigma Gillingham, Dorset UK. Roswell Park Memorial Institute medium (RPMI-1640), trition X-100 (CAS 9002-93-1) Sigma-Aldrich Gillingham, Dorset UK, trizma base (CAS 77-86-1) Sigma Gillingham, Dorset UK, trypan blue (CAS 72-57-1) were purchased from Sigma-Aldrich, Gillingham, Dorset UK. Dimethyl sulfoxide (DMSO) (CAS 67-68-5) and NaOH (CAS 1310-73-2) were purchased from BDH, Poole Dorset UK. Fetal bovine serum and phytohaemagglutinin liquid (CAS 9008-97-3) were purchased from GIBCO Invitrogen Paisley UK. Ibuprofen USP (CAS 15687-27-1) was purchased from Sigma-Aldrich, Gillingham, Dorset UK. Low-melting-point agarose (LMP) (CAS 39346-81-1), normal-melting-point agarose (NMP) and (CAS 9012-36-6) were from Invitrogen, Paisley UK. Lymphoprep (CAS 66720-17-0) was from Axis-Shield, Norway.

2.3. Preparation of nanoparticles.

Aspirin and Ibuprofen were suspended (3% and 4% (w/w), respectively) with solid loads in special suspension medium, which was prepared from melting polyvinylpyrrolidone K-30 (0.5% w/w), hydroxypropyl methylcellulose (HPMC) (0.5% w/w), and sodium lauryl sulphate (0.1% w/w) in deionised water. A Lena nanoceutics technology DM-100 machine was used to mill the suspensions. Yttrium, 0.2 mm, 150
ml, was used to mill a 250 ml portion of each suspension in the presence of stabilised zirconium beads (Glen Mills, USA). Recycling the suspension in the milling machine took 60 min, before discharge and transfer to an impervious glass bottle. The suspensions were stored at 4°C.

2.4. Comet assay

2.4.1. Cell treatment
Twenty stored blood samples each from healthy volunteers and BC patients were allowed to thaw at room temperature. Blood suspension, 100 μl, was added to RPMI-1640 medium, 890 μl, in Eppendorf® tubes, which contained negative control solvent (NC), 10 μl, positive control (PC) (50 μM H$_2$O$_2$), and the test articles: ibuprofen (250 μg/ml) and aspirin (500 μg/ml), in nano and bulk formulations. The alkaline comet assay (pH >13) was performed as described previously [11-14].

2.4.2. Staining and comet scoring
Ethidium bromide (20 μg/ml) stain was used for DNA staining; a 60 μl aliquot of dye was added on the top of each slide and covered with a cover slip. The slides were scored under a fluorescence microscope connected to image analysis software (Andor, Belfast, UK). A 20 x magnification lens was used. 100 cells were selected randomly from each slide for analysis.

2.5. Micronucleus assay (CBMN)
Fresh blood samples from each of five healthy volunteers and five BC patients were used. Before starting the culture, T25 cm³ flasks containing 4.5 ml frozen prepared medium were placed in a 37°C incubator (5% CO$_2$) for 30 min. Sterile materials and solutions were used when performing lymphocyte 72 h cultures. The protocol was as described by Fenech [15], [16].
Various cytological scoring parameters were used, including cell mitotic status, mononucleated cells (monoNC), binucleated cells (BiNC), multinucleated cells (MultiNC), nuclear division index (NDI), and chromosomal damage/instability parameters in the form of nucleoplasmic bridges (NPBs) and nuclear buds (NBUDs) in lymphocytes. MNi, NBP, and NBUDs were scored in BiNC up to 500 cells. 500 other cells were scored to calculate the percentages of each type of cells: monoNC, BiNC, and MultiNC. After scoring proportions, three cell types were used to calculate the NDI, to measure the rate of mitotic division and cytostatic effects [15].

2.6. Aspirin and ibuprofen concentrations

Two different sizes of ibuprofen and aspirin were used (NPs and bulk), using the same concentrations for both sizes. The concentration were 250 µg/ml Ibuprofen and 500 µg/ml aspirin. These concentrations were selected according to the differences in properties of the two drugs and did not cause cytotoxicity/ apoptosis (data not shown).

2.7. Cell viability

Cell viability was evaluated for lymphocytes after 30 min treatment with ibuprofen or aspirin. Cells were centrifuged in a micro-centrifuge at 450 x g for 5 min at room temperature. Then, 0.4% trypan blue solution was mixed with the cells, 1:1, and 100 cells were recorded.

2.8. Statistical analysis

Data were analysed using Graphpad and SPSS 18.0. (one-way ANOVA) and p ≤ 0.05 was considered significant.
3. Results

The percentages of smokers were 11% (healthy controls) and 35% BC patients. We believe that neither smoking status nor ethnicity confounded the responses, in view of the uniformity of the data; the t-test showed no significant differences between smoking status and ethnicity in the control and patient groups.

Figures 1a and b show the comet assay concentration responses of the nano and bulk formulations of ibuprofen on lymphocyte DNA from BC patients and healthy controls, using Olive tail moment and % tail DNA parameters. Ibuprofen reduced lymphocyte DNA damage among BC patients but the reduction was not statistically significant.

Figures 2a and b show the corresponding data sets for aspirin. Aspirin significantly reduced lymphocyte DNA damage for BC patients. However, healthy control samples showed weak and non-significant damage increases, compared to untreated cells.

Neither aspirin nor ibuprofen showed significant differences between the bulk and nano forms.

Tables 2a and b show the CBMN assay results following exposure to ibuprofen and aspirin, NPs and bulk, with respect to the cytological scoring parameters for lymphocytes from five female volunteers and five BC patients. In general, MN frequencies were reduced by both ibuprofen and aspirin.

4. Discussion

Various studies [5, 6] have suggested that NSAIDs can prevent tumours, including BC, and this protective effect may be mediated by pathways involving inhibition of
COX1 and COX2 and the expression of tumour suppressor genes such as p53 [22, 23]. Ibuprofen and aspirin are the most commonly used NSAIDs [5, 6, 24]. In this work, ibuprofen and aspirin, NPs and bulk, were studied for their protective effect on DNA damage in BC patients, using lymphocytes as surrogate cells.

Generally, both aspirin and ibuprofen caused a reduction in DNA damage and MN formation in lymphocytes from BC patients. Aspirin, both bulk and nano sizes, gave a significant reduction in DNA damage in both the comet and MN assays. Ibuprofen, in contrast, showed a significant reduction with the MN assay, with both NPs ($P \leq 0.001$) and bulk forms ($P \leq 0.01$), but any effect in the comet assay was weak or insignificant. Note that the incubation times for the comet assay (30 min) and MN assay (72 h) are very different, which may explain the different results. This explanation is consistent with the fact that NPs have better penetration through nuclear membranes, due to their smaller sizes compared to the bulk form.

Ibuprofen genotoxicity has been debated. Genotoxicity of ibuprofen in *Salmonella* strains was inconclusive [25]. Philipose *et al* [25], on the other hand, demonstrated genotoxicity of ibuprofen in mice, namely the induction of sister chromatid exchange. Ghosh *et al* [26] found that ibuprofen had no genotoxic effect over a short period (two weeks) in human peripheral whole blood cells and isolated lymphocytes. Tripathi *et al* [27] conducted a similar study to investigate ibuprofen genotoxicity in mouse bone marrow cells. They concluded that ibuprofen has a genotoxic effect and that this effect was more pronounced at 40 and 60 mg/kg b.w. doses than at 10 and 20.

Aspirin is not genotoxic. A protective effect was observed in mice when aspirin (doses 0.5, 5, or 50 mg/kg b.w.) was combined with the genotoxic anticancer agent mitomycin (MMC, 2 mg/kg b.w.). Aspirin reduced the genotoxicity of MMC in the liver
and spleen, in a dose-dependent manner [28, 29]. These findings are in accord with the outcomes of our study. Niikawa et al. [28] suggested that aspirin many act by scavenging reactive oxygen species.

Inhibition of cyclooxygenase is the mechanism most commonly proposed for aspirin’s protective activity. COX enzyme has an important function in the synthesis of prostaglandin endoperoxides. Prostanoids, including prostaglandins, are essential biological mediators and serve various biological roles. Three forms of COX are known: COX1, COX2, and COX3. Aspirin and ibuprofen can block both COX1 and COX2; their inhibition effects are greater on COX1 [30]. Prostaglandins have roles in cell division, migration, angiogenesis, and apoptosis [31]. In addition, many preclinical studies have found that the pro-inflammatory compound prostaglandin E2 (PGE2) catalyses oestrogen production by increasing expression of aromatase. Aromatase, a cytochrome P450 enzyme, catalyzes production of oestrogen from androgens. COX enzymes stimulate PGE2 production, CYP19 transcription, and aromatase activity. These findings are consistent with the observation of a positive correlation between COX enzyme levels and CYP19 expression in human breast carcinoma [32]. The breast cancer prevention effects of aspirin and ibuprofen may be linked to inhibition of prostaglandin production and, ultimately, oestrogen production and mammary cell proliferation [7].

5. Conclusions

Ibuprofen and aspirin, both bulk and NP forms, reduced comet assay DNA damage in lymphocytes from BC patients but not in healthy volunteers. The MN assay data showed a decrease in MN frequency, which followed a similar pattern to the results for the comet assay. In both assays, aspirin was more effective than ibuprofen. NPs of both agents were more effective than the bulk formulations. Our
results are consistent with the hypothesis that NSAID have a promising role in BC prevention and treatment.
6. References

Table 2a Cytological scoring parameters in lymphocytes from five healthy females following exposure to ibuprofen and aspirin (NPs and bulk).

<table>
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<th>Chemical conc</th>
<th>NDI</th>
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<th>MNi mean</th>
<th>NPBs mean</th>
<th>NBUDs mean</th>
<th>% MultiNC</th>
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<td>1</td>
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<td>Aspirin NPs</td>
<td>500 ng/ml</td>
<td>2.0</td>
<td>69.4</td>
<td>2 (ns)</td>
<td>0</td>
<td>0</td>
<td>17.6</td>
</tr>
<tr>
<td>Aspirin bulk</td>
<td>500 ng/ml</td>
<td>1.9</td>
<td>74</td>
<td>2 (ns)</td>
<td>0</td>
<td>0</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Conc = concentration  
NC = negative control  
PC = positive control  
NPs = nanoparticles  
NDI = the nuclear division index  
BiNC = Binucleated cells, % BiNC, is % expressed out of all types of 500 cells scored.  
MultiNC = Multinucleated cells % MultiNC, is % expressed out of all types of 500 cells scored.  
MNi = Micronuclei score/500 cells each of BiNC  
NPBs = nucleoplasmic bridges  
NBUDs = nuclear buds  
All groups are compared to the negative control (NC), using * $p = < 0.05$, ** $p = < 0.01$, *** $p = < 0.001$ for significance and ns (ns) = not significant.
Table 2b  Cytological scoring parameters in lymphocytes from five BC patients following exposure to ibuprofen and aspirin (NPs and bulk).

<table>
<thead>
<tr>
<th>Treatment group</th>
<th>Chemical conc.</th>
<th>NDI</th>
<th>% BiNC</th>
<th>MNi mean</th>
<th>NPBs mean</th>
<th>Buds mean</th>
<th>% MultiNC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspension buffer (NC)</td>
<td>2.0</td>
<td>67.9</td>
<td>11.4</td>
<td>1.4</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Mitomycin C (PC)</td>
<td>0.4 µM</td>
<td>1.9</td>
<td>69.1</td>
<td>17.6 **</td>
<td>2.4</td>
<td>2.4</td>
<td>13.3</td>
</tr>
<tr>
<td>Ibuprofen NPs</td>
<td>250 ng/ml</td>
<td>1.8</td>
<td>67.5</td>
<td>5 ***</td>
<td>0</td>
<td>0</td>
<td>8.6</td>
</tr>
<tr>
<td>Ibuprofen bulk</td>
<td>250 ng/ml</td>
<td>1.8</td>
<td>65.3</td>
<td>6 **</td>
<td>0</td>
<td>0</td>
<td>6.4</td>
</tr>
<tr>
<td>Aspirin NPs</td>
<td>500 ng/ml</td>
<td>1.8</td>
<td>65.8</td>
<td>3.2 ***</td>
<td>0</td>
<td>0</td>
<td>8.2</td>
</tr>
<tr>
<td>Aspirin bulk</td>
<td>500 ng/ml</td>
<td>1.9</td>
<td>67.6</td>
<td>3.4 ***</td>
<td>0</td>
<td>0</td>
<td>9.3</td>
</tr>
</tbody>
</table>

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All groups are compared to the negative control (NC), using * p = < 0.05, ** p = < 0.01, *** p = < 0.001 for significance and ns (ns) = not significant.
**Figure legends**

**Figure 1a** Comparison of ibuprofen concentration responses, ±SE, and significance levels in DNA from lymphocytes DNA from healthy volunteers and BC patients using Olive tail moment. N=20

**Figure 1b** Comparison of ibuprofen concentration response, ±SE, and significance on lymphocytes DNA from healthy volunteers and BC patients; % tail DNA. N=20

**Figure 2a** Comparison of the aspirin concentration response, ±SE, and significance level in DNA from lymphocytes DNA from healthy volunteers and BC patients; Olive tail moment. N=20

**Figure 2b** Comparison of the aspirin dose response, ±SE, and significance on lymphocyte DNA from healthy volunteers and BC patients; % tail DNA. N=20
Figures

Figure 1a

![Graph showing olive tail moment for different treatments]

- **a** = comparison with untreated cells
- **b** = comparison of bulk with nano

**ns** = not significant

***** = significance ($p \leq 0.001$)
**Figure 1b**

![Graph showing olive tail moment for different treatments.]

- **Healthy volunteers**
- **DC**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Olive tail moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated Cells</td>
<td>5 ± 1</td>
</tr>
<tr>
<td>PC</td>
<td>10 ± 2 ***</td>
</tr>
<tr>
<td>ASP BULK</td>
<td>7 ± 1 ns</td>
</tr>
<tr>
<td>ASP NPs</td>
<td>6 ± 1 ns **</td>
</tr>
</tbody>
</table>

- a = comparison with untreated cells
- b = comparison of bulk with nano

ns = not significant

* = significance (p ≤ 0.0)

** = significance (p ≤ 0.01)

*** = significance (p ≤ 0.001)
Figure 2a

%Tail DNA

Treatment

a = comparison with untreated cells
b = comparison of bulk with nano

ns = not significant

*** = significance (p ≤ 0.001)
Figure 2b

![Bar chart showing % Tail DNA across different treatments.

Legend:
- Healthy volunteers
- BC

- a = comparison with untreated cells
- b = comparison of bulk with nano

- ns = not significant
- * = significance (p ≤ 0.0)
- ** = significance (p ≤ 0.01)
- *** = significance (p ≤ 0.001)