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Biological effects of melt spinning fabrics composed of 1% bioceramic material

Ting-Kai Leung[1], Jian-Min Lin[2], Huan-Sheng Chien[2] and Tzy-Chin Day[1]

Abstract

This study evaluated the usefulness of bioceramic materials (ceramic materials that emit high-performance far-infrared (FIR) rays), processed into fabrics using a traditional manufacturing melt spinning method. Numerous measurements were designed to test the biological functions of 1% bioceramic fabrics. These included physical induction of intracellular nitric oxide (NO) in NIH 3T3 cells (mouse fibroblasts), the effects on cell viability in osteoblastic cells (MC3T3-E1) under hydrogen peroxide-mediated oxidative stress, and the effects on lipopolysaccharide (LPS)-induced cyclo-oxygenase-2 (COX-2) and prostaglandin E2 (PGE2) production in a chondrosarcoma (SW1353) cell line. When compared to the control group, the bioceramic fabrics were capable of inducing further intracellular NO production using NIH 3T3 cells, and maintaining increased viability and against cell intoxication of osteoblastic cells by suppressing cell release of lactate dehydrogenase (LDH) under oxidative stress. In addition, it was found to suppress LPS-induced COX-2 production more significantly in a SW1353 cell line. These processes represent the biomolecular changes occurring during promotion of decline in aging, prevention of osteoporosis, and prevention of inflammatory processes within the human body. Therefore, these bioceramic fabrics are likely to fulfill their claims of having health-promoting benefits.

Keywords

Fabrication, performance, materials

Introduction

Maintaining warmth and being decorative and stylish are fundamental requirements for garments. Wearing garments composed of fabrics that provide health-promoting benefits is an attractive concept for the growing aging population worldwide.[1,2] However, no existing specialized field combines medical and textile technologies to research these materials.

The present study performed a general survey on fabric samples from markets in Asian counties, including some garments manufactured of fibers produced using the melt spinning method and others that had surfaces post-processed with mineral ore additives. In addition, this study measured ionizing radiation emissions. The main sources of ionizing radiation in mineral ore are rare radioactive elements (such as uranium or radium). Previous studies have observed that low doses of ionizing radiation have immunological modulatory effects. Short exposure to low-dose radiation influenced T-cells and macrophages,[3,4] resulting in short-term amelioration of autoimmune diseases. However, exposure of tissues to low-dose ionized radiation for longer periods is not absolutely safe, increasing the possibility of DNA mutations and deletions, and leading to cancer risk.[5–7]

Ionizing radiation has higher frequency ranges and shorter wavelengths than does the visible light spectrum (of 400 to 750 nm) and, therefore, may have sufficient energy to break chemical bonds. High-energy ionizing radiation can also strip off electrons or break up the nuclei of atoms.[5–7] Non-ionizing radiation has lower frequency ranges and longer wavelengths than does the visible light spectrum. Non-ionizing radiation rarely has sufficient energy to break chemical bonds.

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Far-infrared (FIR) radiation (3–1000 μm) consists of invisible electromagnetic waves, with wavelengths longer than visible light, and is the major heat-transmitting radiation at wavelengths of 3 μm to 1 mm, as defined by the CIE (1987). Particularly in the range of 8–14 μm, FIR was suspected to have many biological effects.[8]

This spectrum of wavelength transfers energy that thermoreceptors in the skin perceive as heat. In previous years, people had believed that the optimal wavelength most effective for life is between 8 and 14 μm.[9–16]

Numerous published medical studies have used FIR with a heat supply source to demonstrate that the FIR wavelength increased skin microcirculation in rats, improved blood flow of arteriovenous fistulas in hemodialysis patients, extended survival of skin grafts, and had other health-promoting effects.[17–22] However, these studies have utilized an FIR application with a heat source dependent on electricity, which is inconvenient for wider application during everyday life.

In Asian garment markets, an increasing numbers of products contain fiber additives, such as bamboo charcoal and mineral ores, which the manufacturers claim can promote health when worn on the body. Garments composed of bamboo charcoal have putative health-promoting functions.[23] Although the authors cannot deny the health benefits of these products in maintaining warmth, observing physiological responses to the fabrics in clinical practice has indicated that these products cannot be defined as actual health-promoting materials.[21,24–33] However, further objective analyses are necessary for confirmation.

Assessing some of the samples available on the market did not verify these biological functions as claimed by the product advertisement. Examination also revealed that some of the samples emitted ionizing radiation, which is potentially hazardous to public health.[34,35]

People may believe that a special invisible light spectrum can promote human health. However, lack of thorough investigations, general knowledge, and professional education indicates that the public is incapable of discerning between non-ionizing and ionizing radiation. Even within the fields of materials science and textiles, some confusion exists regarding the concept of radiation. Therefore, manufacturers producing clothing contaminated with ionized radiation, unbeknown to the consumer, is possible.[23]

The emissive efficiency of the FIR ray spectrum cannot be measured using ordinary types of instruments. Thus, mainstream medical applications cannot easily identify FIR.[36,37] In our previous study,[9] we applied two research methods to living human bodies to: (i) measure the possible biological functions of a garment using infrared thermography to produce thermal images; and (ii) observe the real-time dynamic status within the microvasculature of the dorsal human fingertip, based on vascular corrosion casting, using a stereoscopic microscope.[9] Recording the physiological parameters before and after the textile made contact with the skin enabled determining its biological functions. However, human physiological responses, such as body temperature and microcirculation, are constantly changing and have numerous influencing factors. Therefore, these two human tests, though easily performed, have dubious objectivity unless investigators strictly control all of the experimental procedures.

The current study was a collaborative work of professionals from different fields, including medical radiology, clinical sciences, biomedical sciences, and textiles engineering. This study created and researched a new type of ceramic compound that emits an effective electromagnetic wavelength, as confirmed by previous molecular biology studies.[9–16] Our earlier publications investigating bioceramic materials (ceramic materials that emit high-performance FIR rays) focused primarily on the basic medical science of cells and animal models, and we showed that bioceramic materials promote microcirculation and have other effects by upregulating calcium-dependent nitric oxide and calmodulin in different cell lines.[12,16] An inhibitory effect of bioceramic material on murine melanin cancer cell (melanoma) growth was reported.[38] We also demonstrated that bioceramic material has an antioxidant effect by increasing the hydrogen peroxide-scavenging ability of various cells, including murine macrophages (RAW264.7),[15] murine calvaria-derived osteoblast-like cells (MC3T3-E1),[10] NIH 3T3 fibroblast cells,[16] and murine myoblast cells (C2C12).[13] A physical-chemical test platform was also developed to examine other characteristics.[9,11]

Our mission has been to develop fabrics containing bioceramic materials capable of being applied in regular textile manufacturing processes. Because it is difficult and expensive to embed higher than 1% by-weight of bioceramic granules into fiber using a melt spinning procedure to manufacture bioceramic fabrics, whether or not the biological function can be preserved as the original material powder is unknown. As is widely known, 1% solid content in the melt spinning process is commonly used, and the fiber spinning process needs less adjustment. Otherwise, the fiber is easily broken during the spinning and texturing processes; therefore, we choose a 1% bioceramic material as the final composition in the nylon fiber. Thus, this study evaluated the health-promoting and biological functions of assayed textiles and garments (1% by-weight of bioceramic) based on measurements of intracellular nitric oxide (NO) production, antioxidant effects such as bone-forming cell viability under oxidative stress, and

anti-inflammatory effects, especially concerning joint diseases.

Materials and methods

FIR ceramic powder

This study used a ceramic powder composed of micro-sized particles produced using several ingredients, mainly mineral oxides, provided by the Materials Laboratory of Taipei Medical University (Figure 1).[9–16,38] The known ingredients (TiO_2, SiO_2, Al_2O_3, ZnO, and MgO) of the FIR ceramic powder were combined to form a bio-organically harmless formula, based on conclusions from our previous studies.[9–16,38]

The average optimal emission wavelength of the ceramic powder is between 8 and 14 μm, as confirmed by the Industrial Technology Research Institute (Hsinchu City, Taiwan), and represents an extremely high ratio of FIR ray intensity.[36,37] Bioceramic material was ground into a powder using a grinding process consisting of two stages, wet and dry grind. The powder was prepared by further pulverizing it to a suitable size for adoption in the melt spinning procedure, using various types of fibers such as nylon or PET fibers.

Preparing bioceramic fabrics and assessing biological functions

A functional bioceramic powder with a desired size of approximately 200 nm was blended with a matrix polymer, such as PET or nylon, using a twin-screw melt compounding procedure, which was also used to obtain masterbatch chips containing bioceramic powder. In creating a nylon/bioceramic polymer compound, nylon polymer was selected as the matrix because it is soft to the touch when spun into a fiber.

A dispersing agent was usually required to improve the segregation of the bioceramic particles. The dispersing agent we used is a WAX-type of surfactant, which could melt at approximately 180°C or higher. Formulated adjuvants are added for numerous reasons, including improved mixing and handling, increased effectiveness and safety, more efficient distribution, and drift reduction.

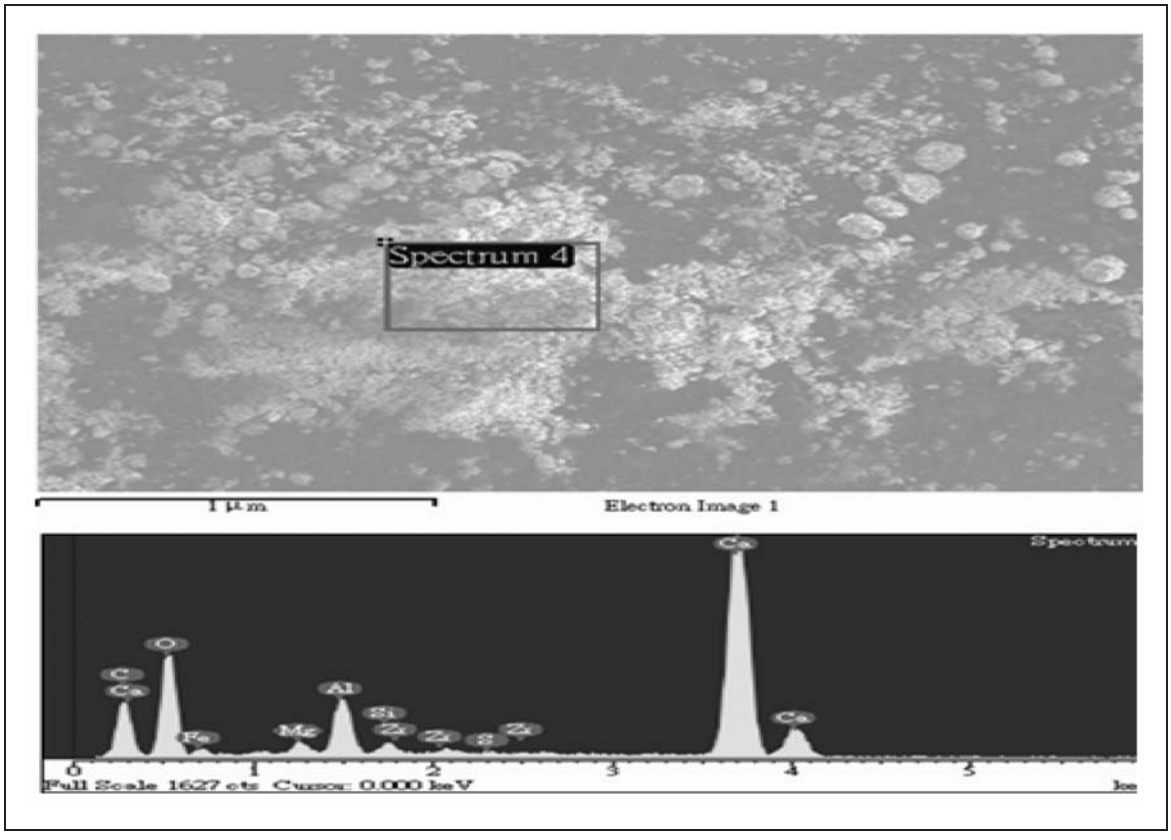

Figure 1. Elemental analysis of the ceramic powder with cFIR irradiation using electron microscopy equipment with electron beam processing on the selected spectrum, which are listed as: calcium (Ca), zirconium (Zr), sulfur (S), silicon (Si), aluminum (Al), magnesium (Mg), iron (Fe), oxygen (O), and carbon. The relative concentration of these main elements (originally as different elemental oxide) is showed in the above figure.

Through the blending process, a masterbatch chip with a desired function was obtained (Figure 2). A masterbatch chip was added to the matrix polymer in the melt spinning process. Varying the number of masterbatch chips can adjust the effective concentration of the bioceramic material in the fiber. Therefore, fine denier fibers incorporated with functional bioceramic particles were obtained via the melt spinning process. After the drawing and twisting processes, a yarn with a desired function was produced (Figure 3). The terminal fabrics, containing 1% high-performance FIR ray-emitting bioceramic material, were produced under the supervision of the Taiwan Textile Research Institute (Tucheng, Taiwan).

The diameter of melting spinning fibers (D) could be approximately estimated using the equation $D = 10 \times (\text{fiber denier})^{1/2}$ (μm). For example, our fiber denier is approximately 2 d (70 d/36 f); therefore, the corresponding fiber diameter is approximately 14 μm. Figure 3(b) shows that the diameter of the as-spun fiber is approximately 13 μm, which corresponds to our estimated result.

The SEM image (Figure 4) shows the surface of the nylon/bioceramic masterbatch chip. No clear aggregation is on its surface (the dark portions are holes, not aggregation). We believed that the fiber was easily broken during the melt spinning process when the bioceramic particle aggregated into a larger particle. However, the melt spinning process was smooth and the spinning pack life sustained for several days. Thus, in the author's opinion, the status of aggregation was not heavy. Nevertheless, we do not have direct evidence (cross-section TEM image) to identify the bioceramic particle distribution in the nylon/bioceramic compound fibers.

To summarize, the shape of the powder showed no significant change after the milling, and the grains were unequiaxed, homogenous, and without micro-pores, as observed using an electronic microscope (Figure 4). The ground powder was then embedded with nylon by spinning it with an overall proportion of 1% ceramic within the fiber. The fiber denier we used in the study was approximately 2 denier (70d/36f). The fabrics used in such experiments are weaving fabrics (220 g/m^2). The fabric was cut into 100 square centimeters (10 cm × 10 cm); therefore; we could ensure that each experiment was conducted uniformly.

Inducing nitric oxide (NO) using bioceramic fabrics

Bioceramic fabrics and nonfunctional fabrics of the same size (10 cm × 10 cm) were used as physical treatment sources. Cells were plated at a density of 1×10^5 cells per well into a 6-well cell culture plate. The NIH 3T3 cell type was grown in a suspension and incubated (at 37°C in a 5% CO_2 atmosphere) in the dark until 80% confluence in the bottom of the incubator. Dishes of cell suspension containing the bioceramic fabric (as the experimental group) and the nonfunctional fabric (as the control group) were placed at the bottom of the incubator for 10 min of treatment. All dishes were stained with DAF-FM diacetate for fluorescence measurement. All cells were analyzed, at the single-cell level, using a fluorescence-activated cell sorter (FACS) and flow cytometry. Data were acquired and analyzed, and the mean fluorescence intensities of NIH 3T3 cells were determined. The intensity profiles of the groups were recorded after treatment.

Determining the effects of using bioceramic fabrics on hydrogen peroxide-mediated oxidative stress in osteoblastic cells (MC3T3-E1), subsequently assayed for cell viability using XTT assay

Cell proliferation kits for XTT assay {2,3-bis (2-methoxy-4-nitro-5-sulfophenyl)-5-[(phenylamino) carbonyl]-2H-tetrazolium hydroxide} and WST-8 [2-(2-methoxy-4-nitrophenyl)-3 -(4-nitrophenyl)-5 -(2,4-disulfonyl)-2H-tetrazolium] were used to evaluate cell viability, as

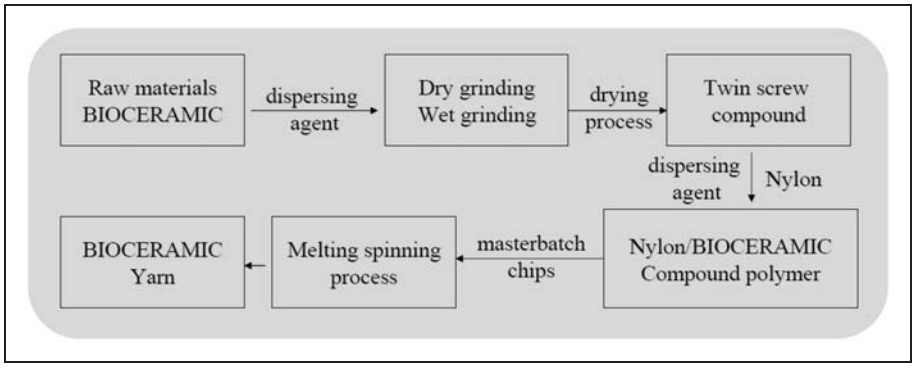

Figure 2. Concept diagram showing the process of bioceramic material, from raw material to functional yarns.

determined by the mitochondrial-dependent reduction to formazone. Cells were plated, at a density of 1×10^5 cells per well, into 24-well plates for 24 h, and treated with H_2O_2 (100 μM). Cells were then treated for an additional 24 h using the control and bioceramic fabrics. Cells were washed three times with phosphate-buffered saline (PBS) (Gibco), and XTT (1 mg/mL) was added to the medium. After three hours, the supernatant was collected. The absorbance was read at 450 nm using an enzyme-linked immunosorbent assay (ELISA) analyzer (Gemini XPS Molecular Devices, Sunnyvale, CA, USA).

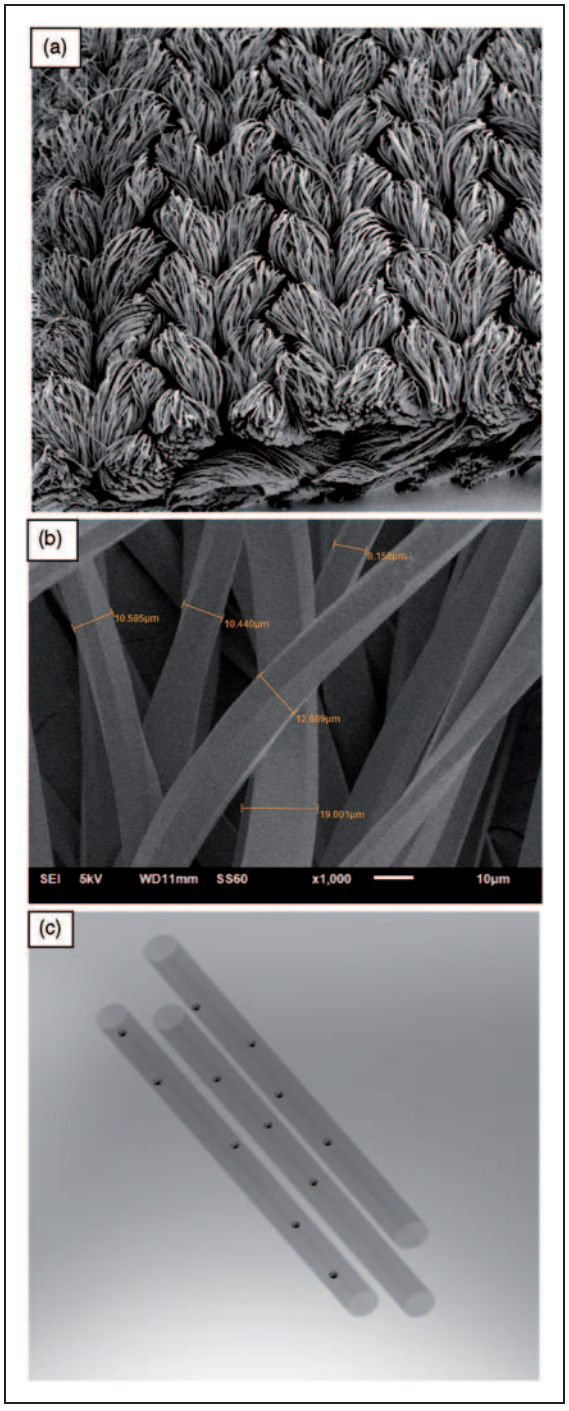

Figure 3. (a)(b) These images, viewed at different magnifications using an electronic microscope, show homogenous PET fibers without observable ceramic powder grains and micropores. (c) Representation of diffuse ceramic embedded within the fabrics using the melt spinning process.

Determining the effects of using bioceramic fabrics on lactate dehydrogenase (LDH) activity release assay under H_2O_2 mediate oxidative stress

Without and with bioceramic fabrics placed beneath the 96-well culture medium discs of MC3T3-E1 cells by 24 h, the percentage of LDH activity release was expressed as the proportion of LDH released into the medium, as compared to the total amount of LDH present in cells treated with the lysis buffer (Roche). The LDH release concentrations of the designated control and cFIR groups of H_2O_2 (200 and 300 μM)-treated cells were analyzed. After 6 h of incubation, the activity was monitored as the oxidation of NADH at 530 nm using an LDH assay kit (Roche).

Determining the effects of using bioceramic fabrics on LPS-induced cyclo-oxygenase-2 (COX-2) production in chondrosarcoma (SW1353) cell line using Western blotting

The chondrosarcoma (SW1353) cells were seeded at a density of 1×10^5 cells/well into a 6-well cell culture plate (GeneDireX, Inc.), one day before the experiment. The cells were then stimulated with 1 μg/mL polysaccharide (LPS) for 24 h, with control and bioceramic fabrics placed beneath the culture medium

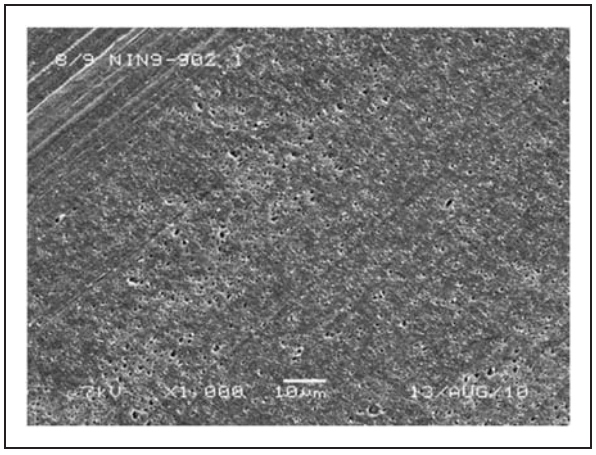

Figure 4. SEM image of the nylon/bioceramic compound polymer chip surface.

discs. Equal amounts of whole cellular extracts were analyzed using 10% SDS-polyacrylamide gel electrophoresis. After electrophoresis, the proteins were transferred to PVDF-nylon membranes.[8] The membranes were then blocked with phosphate-buffered saline Tween-20 (PBST) containing 3% BSA at 4°C overnight. After blocking, the membranes were incubated with first antibodies anti-COX-2 (1:1000) and anti-GAPDH (1:5000) in PBST at 4°C for 20 h (overnight), and then washed four times in PBST for 20 min. Membranes were then incubated with second antibodies (1:10000 in PBST) at room temperature for 2 h, and washed four times in PBST for 1.5 h. After washing, membranes were visualized using ECL detection reagents and autoradiographic film.

Determining the effects of using bioceramic fabrics on LPS-induced prostaglandin E2 (PGE2) production in chondrosarcoma (SW1353) cell line

SW1353 cells were seeded at a density of 2×10^4 cells/well into 24-well cell culture plates (GeneDireX, Inc., Flint Place Poway, CA, USA) one day before the experiment. The cells were then stimulated with 100 ng/mL polysaccharide (LPS) for 24 and 48 h, with control and bioceramic fabrics placed beneath the culture medium discs. The supernatant was harvested and used to measure PGE2 production, using ELISA (R&D Systems, Minneapolis, MN, USA).

Statistical analysis

The statistical significance of differences between the bioceramic fabric group and control group was determined using a paired *t*-test. A *P*-value of <0.05 was considered statistically significant.

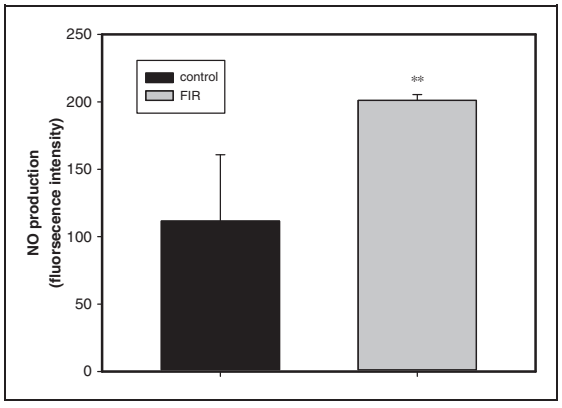

Figure 5. Bars indicate the mean NO synthesized by the bioceramic fabrics (FIR) and control fabrics (control), based on the readings for mean fluorescence intensity of induced NO. $^{**}P < 0.01$, significantly different compared with the control group (n = 8).

Results

NO production in NIH 3T3 cells induced using bioceramic fabrics and control fabrics

Figure 5 displays the levels of NO production induced using the bioceramic and control fabrics. The readings for mean fluorescence intensity showed a significant increase in amounts of NO in the bioceramic fabrics group, as compared to the control group ($P < 0.05$). This result indicated that bioceramic fabrics can induce NO synthesis in NIH 3T3 cells. There was a 74% increase in NO generation in the bioceramic group, as compared to the control group.

Effects of using bioceramic fabrics on osteoblastic cell viability (MC3T3-E1) under H_2O_2-mediated oxidative stress

There were greater numbers of viable cells under H_2O_2-mediated oxidative stress in the group treated

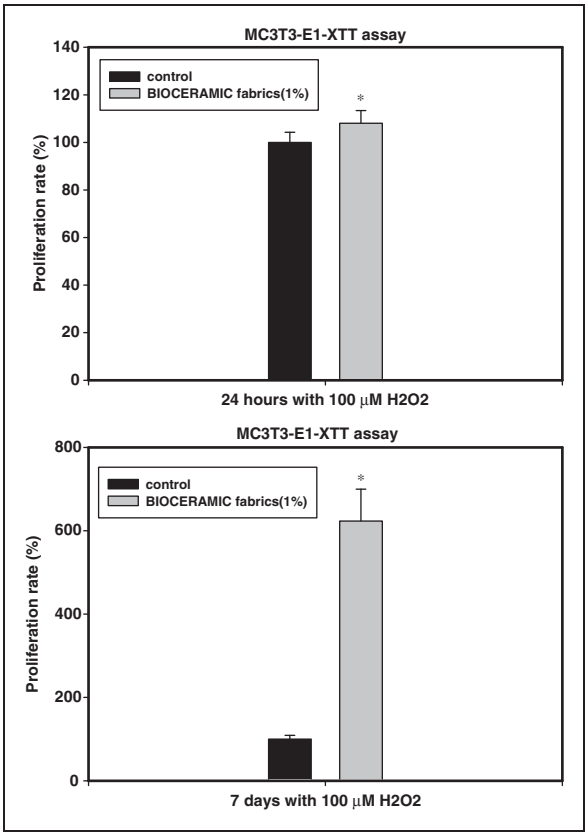

Figure 6. Comparison of LPS-induced PGE2 production in SW1353 cell line in the control and bioceramic fabrics groups after 24 h and 7 days. There is a significantly increased cell survival rate in the bioceramic fabric groups, at both sampling intervals, compared to the control group. $^{*}P < 0.05$, significantly differently compared with the control groups (n = 24).

with bioceramic fabrics than in the control group (Figure 6) ($P < 0.05$).

The *t*-test confirmed the significance of these findings and suggested that bioceramic fabrics treatment reduced cytotoxicity induced by H_2O_2-induced oxidative stress.

Effects of using bioceramic fabrics of LDH activity release assay on osteoblastic cell viability (MC3T3-E1) under H_2O_2-mediated oxidative stress

The effect of using bioceramic fabrics on LDH release assays indicated a significant difference between the control and cFIR groups for H_2O_2-treated cells (200 and 300 μM, $P < 0.05$); the bioceramic fabrics group showed a significant reduction in LDH release (Figure 7).

Effects of using bioceramic fabrics on LPS-induced cyclo-oxygenase-2 (COX-2) production in the chondrosarcoma (SW1353) cell line

The COX-2 accumulation in the culture media was measured following 24 h of 1 μg/mL LPS stimulation, with control and bioceramic fabrics placed beneath the cell medium discs, to investigate the effects of bioceramic fabrics on COX-2 production.

According to results from Western blotting, LPS treatment induced lower levels of COX-2 protein in the bioceramic fabrics group than in the control group (Figure 8). This result reflected significant suppression of LPS-induced cell COX-2 production by the bioceramic fabrics.

Effects of using bioceramic fabrics on LPS-induced prostaglandin E2 (PGE2) production in chondrosarcoma cell line

The PGE2 accumulation in the culture media was measured following 24 and 48 h of 100 ng/mL LPS stimulation, with control and bioceramic fabrics

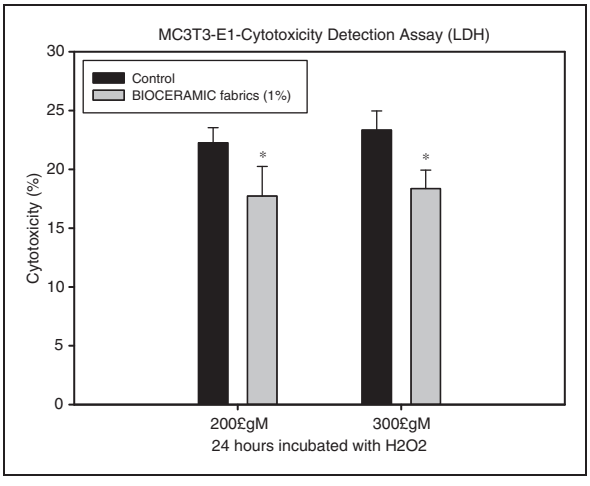

Figure 7. Comparison of H_2O_2-mediated oxidative stress on LDH production in MC3T3-E1 cell line in the control and bioceramic fabrics groups under 200 and 300 μM after 24 h, respectively. Both results show significant decreases of LDH release in the bioceramic fabric groups compared to the control groups. *$P < 0.05$, significantly different compared with the control groups (n = 5).

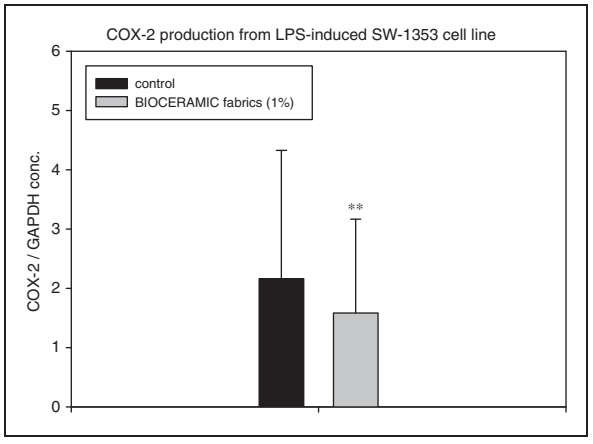

Figure 8. Effects of bioceramic fabrics on LPS-induced cyclo-oxygenase-2 (COX-2) production in the chondrosarcoma (SW1353) cell line. The result shows significant suppression of COX-2 production using the bioceramic fabrics. **$P < 0.01$, significantly differently compared with the control group.

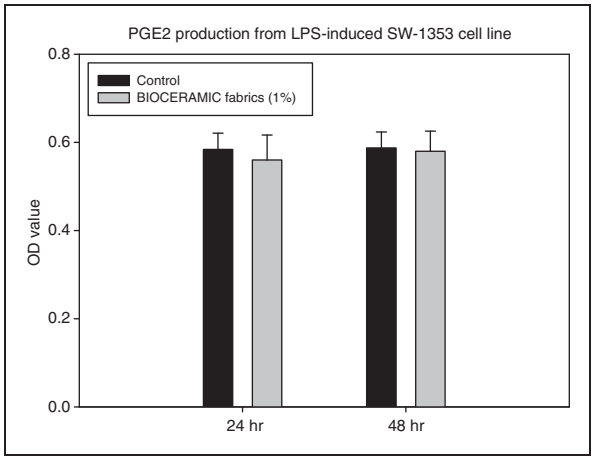

Figure 9. Effects of bioceramic fabrics on LPS-induced prostaglandin E2 (PGE2) production in chondrosarcoma cell line at 24 h and 48 h. The results may suggest suppression of LPS-induced cell PGE2 production using the bioceramic fabrics, though they did not reach statistical significance.

placed beneath the cell medium discs, to investigate the effects of bioceramic fabrics on PGE2 production. The LPS treatment induced lower amounts of PGE2 production in the bioceramic fabrics group than in the control group (Figure 9). This result may suggest suppression of LPS-induced cell PGE2 production using the bioceramic fabrics, though the results did not reach statistical significance.

Discussion

Textile production includes a wide range of post-processing methods prior to application, such as dyeing and setting. Occasionally, surfactants are dissolved in a hot water bath with detergent during the dyeing process. Therefore, we presumed that the amount of dispersing agent residual in the fibers was less, following the textile production process. Most of the dispersing agent could be washed out during the dyeing process in the hot water bath. Although the residual dispersing agent may still have some effects on the anti-bacterial properties, there is no clear evidence to show that the dispersing agent has health-promoting benefits. In the author's opinion, those positive biological effects were a result of the 1% bioceramic material within the fabrics.

According to our previous studies, bioceramic material is capable of increasing the intracellular NO levels produced by calcium-dependent nitric oxide synthetase, which is beneficial to us and limited under many pathological and aging conditions.[13]

The present study shows that using fabrics with 1% bioceramic content also exhibit NO inducing effect on cells. As is widely known, the discovery of cellular NO as a vital signal messenger molecule involved in numerous physiological processes within the human body helped three scientists win the Nobel Prize in 1998. Appropriate levels of NO production are essential for maintaining normal functioning in different mammalian organs. NO participates in a wide range of molecular biological processes, performing vital roles in vessel homeostasis, inhibiting vascular smooth muscle contraction, platelet aggregation, and leukocyte adhesion to the endothelium. Phagocytes (monocytes, macrophages, and neutrophils) also generate NO as part of the human immune response, leading to vasodilation and smooth muscle relaxation, thereby preventing myocardial and cerebral ischemia. NO also participates in the regulation of neurological functions, increases renal function, promotes wound healing processes, and is involved in fertility, penile erection, and prevention of dysmenorrhea.[31,32,33,39–44] Bioceramic manufactured garments may act as remedies, or at least alternative paramedical applications for patients, especially those suffering from the aforementioned diseases.

Bone formation requires differentiated and active osteoblasts to synthesize the extracellular matrix that supports the mineralizing process. Regarding bone and joint studies, our results from this cell model with induced oxidative stress indicated that bioceramic fabrics may have the beneficial effects of preventing oxidative damage to bone tissues. Bioceramic fabrics have also demonstrated potential anti-inflammatory effects on joints, reversing LPS-induced arthritis in an animal model and inhibiting COX-2 production in cell model experiments. The results of this study indicate that bioceramic fabrics can scavenge hydrogen peroxide, increase cell survival, and prevent cell damage reflected by lesser release of LDH under H_2O_2-induced oxidative stress. Lactate dehydrogenase (LDH), a stable enzyme present in all cell types, is rapidly released into the cell culture medium when plasma membranes are damaged. Therefore, LDH is the most widely used marker in cytotoxicity studies.[14,45] In addition, COX-2, an enzyme inducible by LPS, is known to be a key enzyme causing inflammation in rheumatoid arthritis. COX-2 is, therefore, an ideal target of rheumatoid diseases and osteoarthritis.[46,47] The present study revealed that bioceramic fabrics downregulated the LPS-inducing COX-2. Using bioceramic fabrics could potentially protect bone tissue against aging degeneration and the osteoporotic process, relieve the pain of acute inflammatory joint disease, and, thus, help maintain bone health.[48–55]

In the authors' opinion, bioceramic fabrics may fulfill health-promoting or anti-aging claims by partly compensating for human deficiencies during insufficiency and degenerative statuses.

This material can be used to design different garments, and can be widely applied in hospitals and in promoting health. Aside from aging and skeletal disease, using bioceramic fabrics may help patients in the postoperative recovery stage, oncological patients exhausted from chemotherapy and radiotherapy, patients with chronic renal failure who are receiving hemodialysis, and patients suffering from insufficient leg circulation because of uncontrolled diabetes.

This study employed fabrics with 1% high-performance FIR ceramic powder, manufactured traditionally using the cost-effective melt spinning method. Because the obtained fibers containing bioceramic resulted from the melting spinning process, the bioceramic were embedded into the spun fibers and could not easily be washed out. The fabrics can still demonstrate their functions because of the bioceramic remaining in the fibers during the textile production process.

This study evaluated the usefulness of bioceramic materials added into fabrics. Our previous study already confirmed that our original bioceramic powder demonstrates biological functions.[9–16,38]

Conclusion

Based on existing evidence, the newly developed 1% bioceramic fabrics were capable of inducing further intracellular NO production using NIH 3T3 cells, maintaining increased viability and against cell intoxication of osteoblastic cells by suppressing cell release of LDH under oxidative stress. In addition, it was found to suppress LPS-induced COX-2 production more significantly in a SW1353 cell line. These processes represent the biomolecular changes occurring during promotion of decline in aging, prevention of osteoporosis, and prevention of inflammatory processes within the human body. However, additional tests are necessary to ensure quality control for garment manufacturing, and to maintain health-promoting standards.

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