Effects of extracellular modulation through hypoxia on the glucose metabolism of human breast cancer stem cells

IOP Conf. Series: Journal of Physics: Conf. Series **884** (2017) 012026 doi:10.1088/1742-6596/884/1/012026

Effects of extracellular modulation through hypoxia on the glucose metabolism of human breast cancer stem cells

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Abstract. Cancer stem cells have been reported to maintain stemness under certain extracellular changes. This study aimed to analyze the effect of extracellular O_2 level modulation on the glucose metabolism of human CD24-/CD44+ breast cancer stem cells (BCSCs). The primary BCSCs (CD24-/CD44+ cells) were cultured under hypoxia (1% O_2) for 0.5, 4, 6, 24 and 48 hours. After each incubation period, HIF1α, GLUT1 and CA9 expressions, as well as glucose metabolism status, including glucose consumption, lactate production, O_2 consumption and extracellular pH (pHe) were analyzed using qRT-PCR, colorimetry, fluorometry, and enzymatic reactions, respectively. Hypoxia caused an increase in HIF1α mRNA expressions and protein levels and shifted the metabolic states to anaerobic glycolysis, as demonstrated by increased glucose consumption and lactate production, as well as decreased O_2 consumption and pHe. Furthermore, we demonstrated that GLUT1 and CA9 mRNA expressions simultaneously increased, in line with HIF1α expression. In conclusion, modulation of the extracellular environment of human BCSCs through hypoxia shifedt the metabolic state of BCSCs to anaerobic glycolysis, which might be associated with GLUT1 and CA9 expressions regulated by HIF1α transcription factor.

1. Introduction

Many studies on the effort to increase the effectiveness of breast cancer therapy have found that the approach to cancer therapy should consider the role of tumor microenvironment. The environment is defined as the surroundings of cancer cells that comprises two main components: the cellular components, which are composed of tumor stromal cells such as epithelial cells, endothelial cells, fibroblasts, macrophages, immune/inflammatory cells, and mesenchyme stem cells; and the non-cellular components, which comprise structural proteins, extracellular matrix-forming polysaccharides, and soluble factors such as cytokines, chemokines, and growth factors [1,2]. The tumor micro-environment has its own chemical environment that is composed of oxygen tension (O_2), pH, molecule concentration, and small metabolites such as NO, glucose, glutamine, and lactate [3]. The tumor microenvironment is known to have a variation of O_2 tension that depend on the location and quality of nearby blood vessels. Although the tumor can induce angiogenesis, the quality of new blood vessels in tumor tissues are usually poor and the rapid growth of tumors often surpasses the pace of blood vessel formation by endothelial cells. Oxygen supply to the tumor is low and creates a hypoxic state [4,5].

Inside a tumor mass, there is a cancer cell subpopulation that has the pluripotency property similar to that of normal stem cells. This cancer cell population is known as cancer stem cells (CSCs). CSCs are hypothesized as the cell responsible for determining tumor growth (tumorigenic) because of its self-renewal and pluripotency [6,7]. The role of a hypoxic microenvironment in the regulation of the transcription factor, hypoxia inducible factor (HIF), in the maintenance of CSCs is partly known. However, the role of metabolic state in maintaining stemness and survival of human breast cancer stem cells (BCSCs) in a hypoxia still needs to be examined because of the lack of consistent findings in previous studies. Some previous studies showed that BCSCs depend on oxidative phosphorylation, but other studies asserted that BCSCs depend on glycolysis to maintain their stemness [8-13]. The present study is part of a series of research investigating the influence of microenvironment changes on the BCSC metabolic state and how the metabolism affects the survival, tumorigenicity, and stemness of BCSCs.

2. Materials and Methods

2.1. Culture of human BCSCs and hypoxia exposure

In our previous study, the primary culture of human breast cancer cells was sorted using magnetic-activated cell sorting conjugated with anti CD24 and anti CD44 antibody, thus resulting in $CD24^-/CD44^+$ cells for BCSCs and $CD24^-/CD44^-$ cells for non-BCSCs (Patent registration from the General Directorate of Intellectual Property Right, Ministry of Law and Human Right, Republic of Indonesia; No. P0021300369). BCSCs were initially seeded at 5 x 10^5 cells/well in a six-well plate, cultured in 3 mL/well of DMEM-F12 medium (pH = 7.4) containing HEPES buffer, 1% penicillin/streptomycin, 1% amphotericin B, 0.2% gentamycin sulfate, and 14.5 mM $NaHCO_3$, and then incubated at 37 °C in a humidified atmosphere of 5% CO_2 and 20% O_2 for 24 h. For the hypoxia exposure, the seeding medium was replaced with a fresh medium, and the incubation was continued at 37 °C, 1% O_2, 5% CO_2, and 94% N2 for 0, 4, 6, 24, and 48 h, respectively. We conducted a normoxic culture for each incubation period as the control. After each incubation period, the pH of the cell culture medium (pHe) was immediately measured using a pH electrode with a Micro Bulb for a 96-well plate (Hanna®) connected with a pH meter (HI 2210®, Hanna). The BCSCs were harvested by centrifugation at 1000 rpm for 10 min to obtain the cell pellet and culture supernatant for various analyses.

2.2. Quantitative reverse transcription polymerase chain reaction (qRT-PCR)

Total RNA was extracted from the cell pellets using Tripure® RNA Isolation Kit (Roche) according to the manufacturer's protocol. The total RNA concentration was quantified using a spectrophotometer (Varioskan Flash). Samples with an A260/A280 ratio of 1.6–2.0 were considered to be free from DNA and proteins. qRT-PCR was performed using KAPA SYBR FAST® qPCR (KAPA BIO SYSTEMS) in the Exicycler™ 96 (Bioneer). The PCR primer sequences used in this study were HIF1α: 5'-GGCGCGAACGACAAGAAAAAG -3' and 5'-GTGGCAACTGATGAGCAAG-3'; GLUT1: 5'-GCTTCCAGTATGTGGAGCAAC-3' and 5'-GGTCCGGCCTTTAGTCTCAG-3'; CA9: 5'-GGCTACAGCTGAACTTCCGA-3' and 5'- GCCAAAAACCAGGGCTAGGA -3'; 18S RNA: 5'-AAACGGCTACCACATCCAAG-3' and 5'-CCTCCAATGGATCCTCGTTA-3'. The Ct value for each gene was determined, and ΔΔCt was normalized to the designated reference sample. The gene expression values were calculated using the Livak method ($2^{-\Delta\Delta Ct}$).

2.3. HIF1α protein level

Total protein was extracted from 5.0 x 10^5 cells. The HIF1α protein level was assayed using the HIF1A Human ELISA kit (Abcam) according to the manufacturer's protocol. Data were presented per total protein.

2.4. Glucose consumption, lactate production, and lactate dehydrogenase (LDH) activity assay
Glucose consumption was determined by subtracting the glucose concentration in DMEM-F12 (17.5 mM) before incubation from with that remaining in the medium after a certain incubation period. The glucose level was measured using O-toluidine colorimetric assay (Sigma) and a spectrophotometer at 625 nm. To determine the extracellular lactate production, the amount of lactate present in the supernatant of the BCSC culture was determined using the L-Lactate Assay Kit (Abcam) and a spectrophotometer at 450 nm. The LDH activity of BCSCs was analyzed using the Lactate Dehydrogenase Activity Assay Kit (Sigma) according to the manufacturer's procedure.

2.5. Extracellular oxygen concentration assay
Oxygen consumption was determined using sensitive phosphorescent probes that were quenched at the excited state in the presence of oxygen (Extracellular O_2 probe, Abcam). Briefly, after culturing BCSCs for a certain incubation period, the cells were harvested and then transferred to a fluorescence 96-well plate with density of -8×10^4 cells/well. The 10 µl probes from a 1 µM stock solution were dispensed into each well, and 100 µl of preheated mineral oil (30 °C) was added to each well to enhance the assay sensitivity by minimizing interference from ambient oxygen. Probe signals were measured by a fluorescence plate reader equipped with a time-resolved mode preset to 37 °C at 1.5 min intervals for 60 min using excitation and emission wavelengths of 380 nm and 650 nm, respectively.

2.6. Statistical analysis
All data were presented as mean ± standard error means (SEM) of at least triplicates. A p-value of at least <0.05 in the independent t-test was considered statistically significant.

3. Results and Discussion

3.1 Results
3.1.1. mRNA HIF1α expression
To evaluate the success of the hypoxia procedure, the expression of mRNA HIF1α, which is an HIF protein subunit coding gene that is responsive to the decrease in O_2 concentration, was analyzed. Quantification using qRT-PCR shows that the expression of BCSCs $CD24^-/CD44^+$ HIF1α mRNA incubated in a hypoxic state significantly increases compared with the cells incubated in a normoxia. This increase in quantity is parallel with the increase in incubation time. After 48 h of incubation, the HIF1α mRNA expression in hypoxia decreases compared with that in the first incubation time frame but is still higher than the HIF1α mRNA expression in a normoxia (Figure 1A). Lysate examination from BCSCs $CD24^-/CD44^+$ incubated in hypoxia shows an increase in HIF1α protein concentration compared with that in the normoxia up to 48 h of incubation (Figure 1B). The increase in mRNA HIF1α expression and HIF1α protein concentration shows that BCSCs $CD24^-/CD44^+$ is indeed responsive to hypoxia. To evaluate the effect of HIF1α mRNA expression and HIF1α protein concentration from BCSCs $CD24^-/CD44^+$ in a hypoxic state on the genes under its regulation, the CA9 and GLUTI mRNA expressions are quantified. These genes encode pH regulator enzyme, carbonic anhydrase 9, and glucose transporter, respectively. This test is conducted on these genes because hypoxia affects cell metabolism to anaerobic glycolysis, which then causes a decrease in extracellular pH and an increase in glucose consumption by the cells. The results of this study show that the increase in GLUTI and CA9 mRNA expression of BCSCs $CD24^-/CD44^+$ in a hypoxic state is correlated with the increase in HIF1a mRNA expression (Figure 2A and 2B).

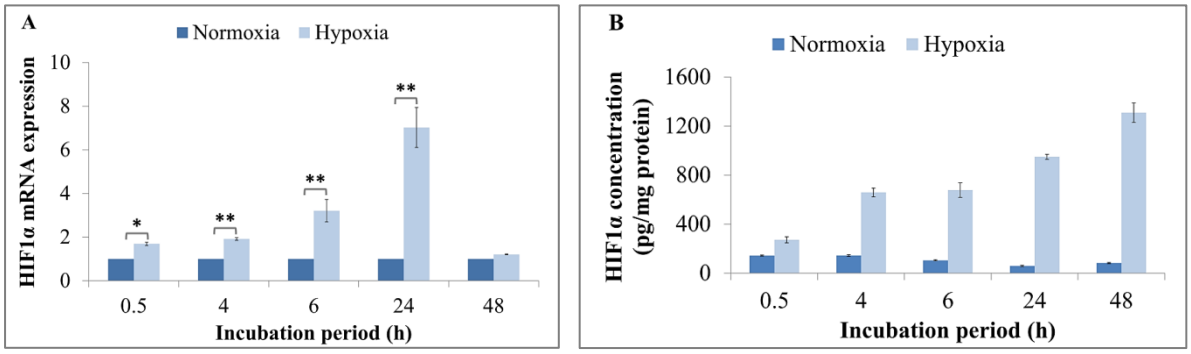

Figure 1. HIF1α mRNA expression and HIF1α protein concentration in BCSCs $CD24^-/CD44^+$ increase in hypoxia. **A**. The HIF1α mRNA expression increases as the incubation period increases and decreases after 48 h. **B**. The HIF1α protein concentration in BCSCs $CD24^-/CD44^+$ lysate cultured in a hypoxia increases. Data are shown as means ± SEM, with T test *p < 0.05; **p < 0.01; n=4

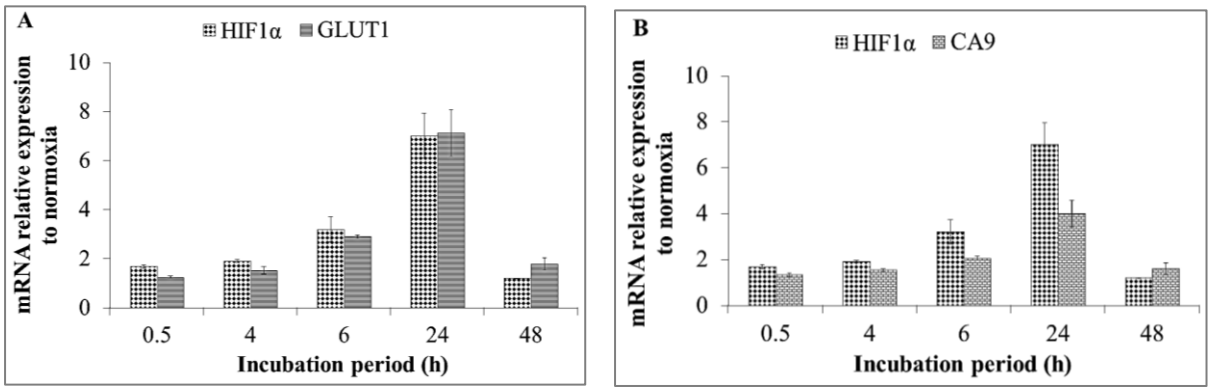

Figure 2. The HIF1α mRNA expression pattern is similar to the GLUT1 and CA9 mRNA expression in hypoxia. **A**. HIF1α and GLUT1 mRNA expression of hypoxic BCSCs $CD24^-/CD44^+$ have the same pattern, with a correlation test result r=0.984 and p=0.002. **B** HIF1α and CA9 mRNA expression of hypoxic BCSCs $CD24^-/CD44^+$ also have the same pattern, with a correlation test result r = 0.983 and p = 0.002. Data are shown as mean ± SEM

3.1.2. BCSCs $CD24^-/CD44^+$ metabolic state in hypoxia

Glucose concentration in the supernatant decreases as the incubation time increases both in hypoxia and normoxia. However, hypoxia causes a faster decrease in glucose concentration than normoxia, particularly after 24 h and 48 h of incubation. The decrease in glucose concentration in the medium shows glucose consumption by the cells. In this study, glucose consumption increases more significantly in hypoxia than in normoxia (Figure 3A). The quantification of lactate concentration in the supernatant shows a difference in lactate production pattern from hypoxic BCSCs $CD24^-/CD44^+$ compared with the normoxic. During 30 min, 4 h, and 6 h of incubation, lactate production in the normoxic group is higher, but not significantly, than that in the hypoxic group. After 24 h and 48 h of incubation, lactate production increases significantly in the hypoxic group. These findings coincide with the quantification of glucose consumption, which experiences an increase after 24 h and 48 h of incubation (Figure 3B). The increase in lactate production is supported by the increase in LDH activity. The results show that the intensity of intracellular O_2 probe of BCSCs $CD24^-/CD44^+$ incubated in hypoxic condition for 0.5, 24, and 48 h is lower than the group incubated in a normoxic condition. An exception is observed in the 48 h normoxic group, which also shows a low O_2 probe intensity. A low probe intensity exhibits a high intracellular O_2 concentration. These results indicate that BCSCs experience anaerobic metabolism during hypoxia. An increase in cell proliferation after 48

h of incubation in normoxia causes the cell metabolism to shift to anaerobic metabolism, which is the characteristic of cancerous cells (Figure 3C). A decrease in pH in the BCSC $CD24^-/CD44^+$ culture medium occurs as the incubation period increases in the hypoxic group (Figure 3D). A decrease in pHe is also observed in the normoxic group. This result shows that BCSCs have a high metabolism rate and that metabolic products such as H^+, lactic acid, and CO_2 cause a decrease in pHe. However, the pHe decrease in the hypoxic group is greater than that in the normoxic group because of an increase in anaerobic glycolysis, which significantly increases acidic metabolism products.

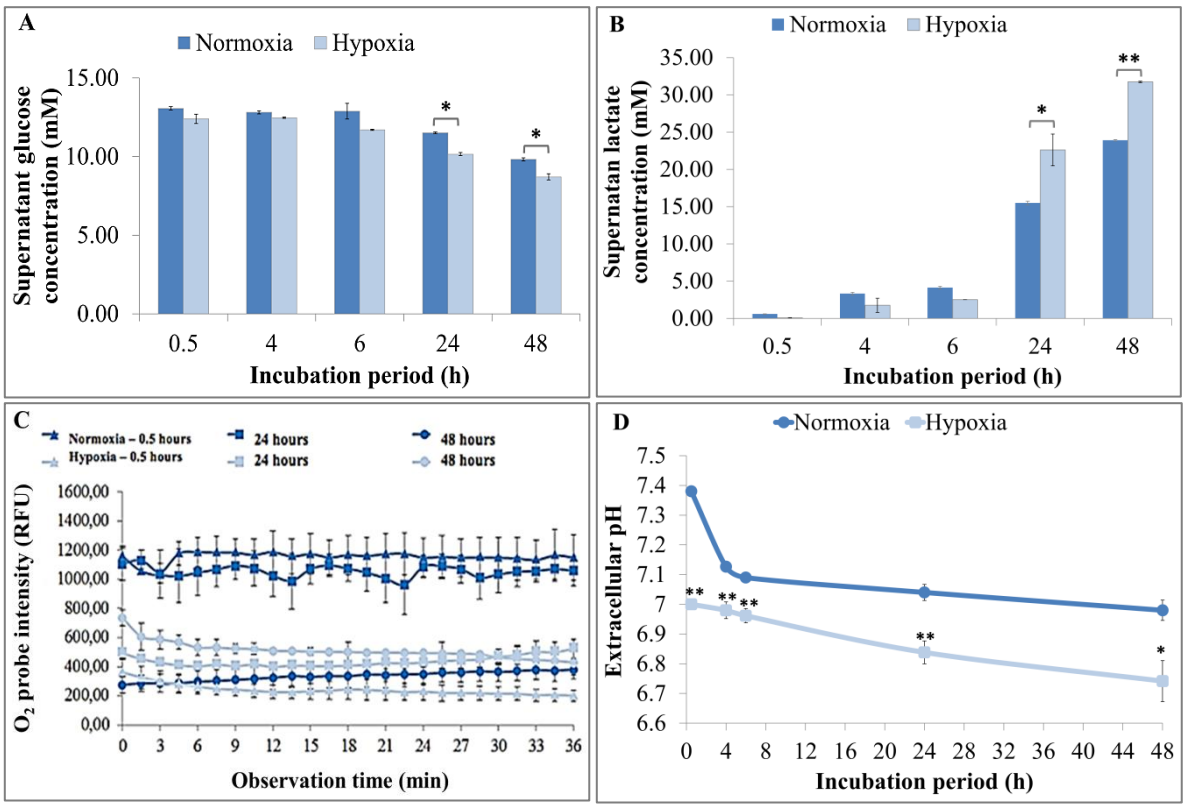

Figure 3. Hypoxia increases the anaerobic metabolism in BCSC $CD24^-/CD44^+$. **A**. Glucose consumption, **B**. Lactate production, **C**. O_2 consumption, and **D**. Extracellular pH. Data are shown as means ± SEM, with T-test results *$p < 0.05$; **$p < 0.01$; n=3. RFU: relative fluorescence units.

3.2 Discussion

In primary tumors, the microenvironment is the main regulator of the CSCs stemness. The interaction between CSCs and the microenvironment is supported by the fact that a disturbance in the environment causes a disturbance in the CSCs [14]. The characteristics of the CSC tumor microenvironment specifically affect its metabolic state. Generally, stem cells show low oxidative phosphorylation activity and high glycolic activity in synthesizing adenosine triphosphate (ATP) [15]. Therefore, CSCs in a hypoxic environment are predicted to depend on glycolysis as their main energy metabolism pathway. This pathway is considered to have an important role in sustaining the stem cell characteristics of CSCs [14,15]. To examine and prove the role of hypoxia in the glucose metabolism status, survival, and stem cell characteristics of CSCs, this study cultured BCSCs $CD24^-/CD44^+$ in a hypoxia with 1% O_2. These conditions were intended to mimic the BCSC microenvironment in a cancer tissue.

The results of this study show that HIF1α is the main regulator of BCSCs $CD24^-/CD44^+$ in a hypoxia. This is observed with a significant increase in HIF1α mRNA expressions and HIF1α protein concentration after exposure to hypoxia but not to normoxia. The increase in HIF1α expression and

stability affects glucose metabolism in two ways. First, HIF1 stimulates energy production through the glycolytic pathway by activating the genes involved in glucose transport into cells (e.g., GLUT1) and enzymes (e.g., such as PFK and aldolase) responsible for intracellular glucose breakdown. Second, HIF1 decreases the oxidative phosphorylation regulation in the mitochondria through the transactivation of genes, such as pyruvate dehydrogenase kinase 1. Both effects reduce the tumor cells' dependence on O_2 when exposed to hypoxia but can still sustain enough energy for the cells [16].

The results of this study indicate a gene expression increase in GLUTI1 BCSCs $CD24^-/CD44^+$ in hypoxia, which is correlated with the increase in HIF1α expression. This increase in GLUTI1 expression is followed with an increase in glucose consumption after 24 h and 48 h. Although this study did not measure the activity of the four key enzymes of glycolysis (i.e., hexokinase, glucokinase, phosphofructokinase, and pyruvate kinase), most of the pyruvates produced were transformed into lactate, as indicated by the increase in LDH activity and lactate production from the cells. These results show that in a hypoxia, HIF1α regulates glucose metabolism in BCSCs $CD24^-/CD44^+$ by increasing the anaerobic glycolytic activity. This action is supported by the decrease in mitochondrial activity exhibited by a low O_2 probe intensity and increased acid production, which lowers the pHe significantly. This study also measured the CA9 gene, which is regulated by HIF1. The results show that in hypoxia, the CA9 gene expression in BCSC $CD24^-/CD44^+$ increases and correlates with the increase of HIF1α mRNA expression. Previous studies found that CA9 in breast cancer cells increased in hypoxia (1% O_2) under the regulation of HIF1α and possibly HIF2a [17]. Other studies on esophagus cancer found that CA9 could be an intrinsic marker in hypoxia and play a role in tumor growth and survival [18].

In hypoxia, the glycolytic metabolism is predominant. That is, cells put in effort to sustain intracellular pH in the physiological range. CA9, as an extracellular anhydrase carbonate, plays a role in regulating extra- and intracellular pH. CA9 activity facilitates pH changes that are expelled by the cells as CO_2 and lactic acid is its conjugate (HCO_3^- and lactate) [19,20]. This CA9 activity is primarily determined by metabolic activities inside the cell to sustain an intracellular pH of 7.2, which is the pH needed for cells to grow [21]. The BCSCs $CD24^-/CD44^+$ CA9 mRNA expression observed in this study might be an effort from cells to convert high acid production (H^+), the product of anaerobic glycolytic metabolism, through rehydration reaction of CO_2 to HCO_3^-. The HCO_3^- is then transported to the cell by a natrium bicarbonate co-transporter (NBC) or by a Na^+ dependent Cl^-/HCO_3^- exchange [20,21]. These conditions continue to lower the pHe as the incubation period extends.

4. Conclusion

The extracellular microenvironment modulation by hypoxia exposure increases the anaerobic glycolysis metabolism in BCSCs $CD24^-/CD44^+$ by increasing glucose consumption, lactate production, LDH activity, and rapid decrease of pHe. The increase in anaerobic glycolysis is regulated by HIF1α. These results show that the metabolic response to environmental change of BCSCs $CD24^-/CD44^+$ is similar to that of normal cells. Therefore, the impact of BCSCs $CD24^-/CD44^+$ metabolic changes as the response to the microenvironment disturbance toward stemness and survival must be studied further.

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Fwd: Announcement Letter PTMDS 2017 (124_PTMDS)

2 messages

Septelia Inawati Wanandi <septelia@gmail.com> Thu, Jul 6, 2017 at 9:24 AM
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Dear Ika,
Ini jawaban dari UIANA.
Tlg dilihat sptnya papernya belum dimasukkan yang kita sudah revisi ya.
Tks.
Salam,
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Mrs. Sri Widya A. Jusman
Biochemistry and Molecular Biology Department
Faculty of Medicine
Universitas Indonesia, Jakarta, Indonesia
E-mail: sriwidiaaj@gmail.com

Dear Mrs. Sri Widya A. Jusman,

Hereby I would like to update you regarding the UI-ANA papers processed by Research & Innovation Product Management Office Universitas Indonesia.

On behalf of the Organizing Committee, I am pleased to inform you that your article entitled “Effects of extracellular modulation through hypoxia and alkalinization on the glucose metabolism and survival of human breast cancer stem cells” has been accepted for poster presentation at The 1st Physics and Technologies in Medicine and Dentistry Symposium (PTMDS 2017) which is being held on 15-16th July 2017 in The Margo Hotel, Depok, Indonesia.

Your paper is under consideration to be published in Journal of Physics: Conference Series. Please find attached your camera ready paper and the Copyright Form of Journal of Physics: Conference Series for your perusal. The completed and signed copyright form should be sent to scholar@ui.ac.id. We will update you at earliest possible regarding the symposium's & registration schedule.

If you need any inquiries regarding PTMDS 2017, do not hesitate to contact us. I look forward to your confirmation. Congratulations and best wishes.

Head of Research and Innovation
Product Management Office

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Dear Dr, Diah,
Thank you for accepting our paper ("Effects of extracellular modulation through hypoxia and alkalinization on the glucose metabolism and survival of human breast cancer stem cells") for the presentation at PTMDS 2015 and publication.

Since part of the paper has been accepted for publication in the in the international journal, we have revised the title and content of our paper.
Previously, we have sent the revision of this paper to the secretariat of FKUI Research Manager (FKUI) to be forwarded to the PTMDS organizing committee.

The revised title of our paper is "Effect of extracelullar modulation through hypoxia on the glucose metabolism of human breast cancer stem cells".

We will send you the revised paper soon.
Apologize for this miscommunication. Hopefully we could still modify this paper.
Looking forward for your confirmation.

Many thanks.
Sincerely,
Dr. Septelia Inawati Wanandi
[Quoted text hidden]

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The 1st Physics and Technologies in Medicine and Dentistry Symposium

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PREFACE

Physics is a fundamental natural science, and its applications extend universally. These includes the application in diagnostics, treatments, biomedical engineering, and materials science in medicine and dentistry. Biomedical sciences are a set of applied sciences applying portions of natural science or formal science, or both, to develop knowledge, interventions, or technology that are of use in healthcare or public health. Further, physics are incorporated in bioengineering principles and practices that are used in hospitals, industries and research laboratories.

The 1st Physics and Technologies in Medicine and Dentistry Symposium initially started in 2017. Motivated by the encouraging results of and responses to the increasing research in the biomedicine research. The 1st Physics and Technologies in Medicine and Dentistry Symposium (PTMDS) was held on July 15th-16th, 2017 in The Margo Hotel, Depok, West Java, Indonesia. PTMDS was organized by the Research and Innovation Products Management Office, Universitas Indonesia.

This meeting was aimed at providing the needed forum for scientific communication and interaction among distinguished scientists working in the field physics, medicine, dentistry and related fields. In turn, the symposium on the latest research results was presented, showing development in the field and help to chart our future research directions. The range of topics covered by PTMDS includes materials sciences and technology in medicine and dentistry, biophysics and medical physics, instrumentation and measurement, physics in medical and dental diagnostics, physics in medical and dental therapeutics, and interdisciplinary physics. The orginizing committee received 304 papers from various topics, and 154 papers were selected after going through a strict peer review process, and are submitted for publication in a conference proceeding. Last but not least, we would like to thank the organizing committee and the reviewers for their tremendous support.

The Editors

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All papers published in this volume of Journal of Physics: Conference Series have been peer reviewed thtough processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

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The 1st Physics and Technologies in Medicine and Dentistry Symposium 15 July 2017, Depok, West Java, Indonesia

Accepted papers received: 11 August 2017
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Tooth enamel surface micro-hardness with *dual species Streptococcus* biofilm after exposure to Java turmeric (*Curcuma xanthorrhiza* Roxb.) extract

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Effect of centrifugation at 7,000 g, 8,000 g, and 9,000 g on the salivary protein profile ≥30 kDa

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