Sains Malaysiana 49(8)(2020): 1865-1874
http://dx.doi.org/10.17576/jsm-2020-4908-09

Effect of FGF-2 and PDGF-BB on a Co-Culture of Human Gingival Fibroblasts and Umbilical Vein Endothelial Cells

(Kesan FGF-2 dan PDGF-BB ke atas Ko-Kultur Sel Fibroblas Gingiva dan Sel Endotelial Vena Umbilikal Manusia)

NASAR UM MIN ALLAH, ZURAIRAH BERAHIM*, AZLINA AHMAD & KANNAN THIRUMULU PONNURAJ

ABSTRACT

Gingival recession can be treated by root coverage procedure with tissue graft. The ideal gingiva graft should mimic the properties of the native gingiva. Gingival fibroblasts are main cells that reside in human gingiva, while the endothelial cells are the basis for blood vessel formation. The co-culture of these cells, will help in better understanding of gingival tissue regeneration. This study was aimed to determine the effects of fibroblast growth factor-2 (FGF-2) and platelet-derived growth factor-BB (PDGF-BB) on a co-culture of human gingival fibroblasts (HGFs) and human umbilical vein endothelial cells (HUVECs). In this in vitro *experimental study, the medium for the establishment of monolayer and co-culture of these cells were first optimised. Then, the optimal concentrations of these growth factors were determined by assessing the cell viability using MTT assay. Next, to study the stimulatory effect of these growth factors, both HGF and HUVECs were co-cultured and gene expression analysis for fibroblast and angiogenic biomarkers was assessed using Real-Time RT-PCR. Cell viability assay showed that the effect of FGF-2 on HGF was dose-dependent and was optimum at a concentration of 5 ng mL^{-1}, while that of PDGF-BB on HUVEC was optimum at a concentration of 20 ng mL^{-1}. The stimulatory effect of FGF-2 and PDGF-BB was further supported by the Real-Time PCR results which showed that there is a significant expression of* VIM, COL1A1, FN, CD31, VE-Cadherin, *and* vWF *in the treatment group of both cells after three days of co-culture experiment, compared to control group. This study indicates a possible synergistic effect of FGF-2 and PDGF-BB growth factors in a co-culture of HGF and HUVEC leading to proangiogenic activity.*

Keywords: Co-culture; FGF-2; HUVEC; PDGF-BB; tissue engineering

ABSTRAK

Penyusutan gingiva boleh dirawat menggunakan prosedur penutupan akar bersama geraf tisu. Geraf tisu gingiva yang unggul mestilah hampir menyerupai tisu gingiva yang asli. Fibroblas gingiva adalah sel utama yang terdapat dalam gingiva manusia, manakala sel endotelium adalah asas untuk pembentukan salur darah. Ko-kultur sel-sel ini akan membantu dalam pemahaman yang lebih baik mengenai pertumbuhan semula tisu gingiva. Kajian ini bertujuan untuk menentukan kesan faktor pertumbuhan fibroblas (FGF-2) dan faktor terbitan platlet (PDGF-BB) ke atas ko-kultur sel fibroblas gingiva (HGFs) dan sel endotelium vena umbilikus manusia (HUVECs). Di dalam uji kaji in vitro *ini, media untuk memantapkan kultur sel satu lapisan dan ko-kultur kedua-dua jenis sel tersebut dioptimumkan terlebih dahulu. Berikutan itu kepekatan yang terbaik bagi kedua-dua faktor pertumbuhan ditentukan dengan menilai kebolehidupan sel menggunakan ujian MTT. Seterusnya, untuk mengkaji kesan perangsangan faktor pertumbuhan ini, kedua-dua HGFs dan HUVECs telah menjalani ko-kultur dan analisis pengekspresan gen untuk biopenanda fibroblas dan angiogenik telah dilakukan dengan masa nyata RT-PCR. Asai kebolehidupan sel menunjukkan bahawa kesan FGF-2 ke atas HGF adalah mengikut dos dan optimum pada kepekatan 5 ng mL^{-1}, manakala kesan PDGF-BB ke atas HUVEC adalah optimum pada kepekatan 20 ng mL^{-1}. Kesan rangsangan FGF-2 dan PDGF-BB turut disokong oleh keputusan masa nyata PCR yang menunjukkan pengekspresan* VIM, COL1A1, FN, CD31, VE-Cadherin *dan* vWF *yang signifikan antara kumpulan yang dirawat untuk kedua-dua jenis sel selepas 3 hari menjalani ko-kultur berbanding kumpulan kawalan. Kajian ini menunjukkan bahawa terdapat kemungkinan kesan sinergistik antara faktor pertumbuhan FGF-2 dan PDGF-BB di dalam ko-kultur sel HGF dan HUVEC yang mengarah kepada aktiviti proangiogenik.*

Kata kunci: FGF-2; HUVEC; kejuruteraan tisu; ko-kultur; PDGF-BB

INTRODUCTION

Gingival recession is a complex soft tissue pathology, defined as an apical shift of the gingival margin, causing exposure of the root surface of a tooth (Jati et al. 2016). A wide range of surgical techniques have been proposed for the treatment of gingival recessions over the decades to ensure full root coverage and satisfactory aesthetic results (Shkreta et al. 2018). Among these, the soft connective

tissue grafts are most widely used and considered as a 'gold-standard' due to its high predictability (Gallagher & Matthews 2017). Soft connective tissue grafts are usually harvested from the palate and transplanted at the recession area to replace the receding tissue. Although the root covering is achieved, these grafts are not fully sufficient for the periodontal tissue to regain the physiological functions and it is coupled with certain limitations. These limitations include lack of adequate vascularisation, limited amount of available donor tissue and demand of a second surgical site, resulting in an additional trauma to the patient and associated risks such as pain, infection, donor-site morbidity and risks of rejection by the patient's immune system (Moraschini & Barboza Edos 2016; Zuhr et al. 2014). Pertaining to these limitations, tissue-engineered constructs are currently being explored in the field of biomedical engineering, however, desirable biocompatibility and bio-functionality still need to be explored.

Mass transfer limitation is a questionable challenge in tissue engineering strategies dealing with vascular research. As the tissue becomes thicker, cells existing at 200 μm and greater from the nearest capillaries would undergo hypoxia, followed by cell death. This diffusion limitation becomes increasingly crucial as the volume and cell population of engineered tissue increases. Blood vessels facilitate the transport of nutrients and oxygen via the vascular structure, which promotes cell migration, proliferation, differentiation and extracellular matrix (ECM) production; as well as the delivery of inflammatory cells to defend the host against pathogens (Traore & George 2017). In most tissue-engineered constructs, vascularisation is achieved by using endothelial cells (ECs). Moreover, apart from ECs, different cells population have been used within the same culture environment depending upon the tissue of interest.

Gingival tissue consists of collagen and blood vessels. Fibroblast and ECs are the common cells in this tissue. ECs are the building block of the vascular system and expected to form functional capillary networks in the tissue construct (Song et al. 2018). On the other hand, fibroblasts play an essential role in the angiogenic process through their production of ECM molecules (Um Min Allah et al. 2017). Previous study has been done using dermal fibroblast and human umbilical vein endothelial cells (HUVECs) in a co-culture system for promoting vascularization (Costa-Almeida et al. 2015). However, there is limited knowledge on the interaction of the cells in a co-culture system especially between human gingival fibroblasts (HGF) and HUVEC, which is very important to understand angiogenesis in gingival tissue.

Apart from using heterotypic cell population in a co-culture, exogenous molecules such as growth factors are used to achieve stable and mature vasculature within a construct. Numerous growth factors are known for their ability to actively regulate various functions of cells in tissue regeneration and *in-vitro* culture. FGF-2 and PDGF-BB are known to play important roles in fibroblast and EC activity, however, there is a dearth of information in the literature that assesses the effect of these two angiogenic growth factors on an *in-vitro* co-culture of HGF and HUVEC. Using the tissue engineering principle, i.e. the interaction between heterotypic cells population (HGF and HUVEC) in a co-culture and addition of exogenous growth factors (FGF-2 and PDGF-BB), this study will provide further understanding and aid in developing functional tissue graft for gingival regeneration.

Materials and Methods

Cells and Materials

Commercially available HGFs and HUVECs were used in this study. HGFs were purchased from ScienCell, USA, and HUVECs from Lonza, USA. For cell viability assay, both cells were seeded in a tissue culture 96-well flat-bottom plates purchased from Greiner Bio-One, Germany. For co-culture experiments, ThinCert™ (Greiner Bio-One, Germany) cell culture inserts for 6 well plates were used. Two polypeptide growth factors, fibroblast growth factor-2 (FGF-2) and platelet-derived growth factor-BB (PDGF-BB) were used in this study. FGF-2 as well as PDGF-BB were purchased from Sigma Aldrich, Germany.

Monolayer Culture of HGF and HUVEC

HGFs were cultured in Alpha Minimum Essential Medium (α-MEM, Gibco, USA) supplemented with 10% Fetal Bovine Serum (Gibco, South America), and 1% Penicillin Streptomycin (Pen/Strep) containing 10,000 units of penicillin (base) and 10,000 μg of streptomycin (base)/mL (Gibco, USA). HUVECs were cultured routinely in Endothelial cell growth medium-2 Bullet Kit (EGM™-2). Endothelial Basal Medium-2 (EBM™-2 Medium) purchased from Lonza, USA supplemented with EGM™-2 SingleQuots™Kit consisting of 0.1% human epidermal growth factor, 0.1% vascular endothelial growth factor, 0.1% R3- insulin-like growth factor-1, 0.1% ascorbic acid, 0.04% hydrocortisone, 0.4% human fibroblast growth factor-beta, 0.1% heparin, 2% Fetal bovine serum, 0.1% gentamicin/ amphotericin-B were used to formulate EBM™-2 to EGM™-2. The cultured cells were maintained at 37 °C, 5% CO_2, and 95% humidity. The cells from the 5th to 6th passage in culture were used for subsequent experiments.

Optimisation of Co-culture Medium for HGFs and HUVECs

To study the effect of growth factors in a co-culture of HGFs and HUVECs, it was mandatory to determine the

growth medium in which both cells can proliferate well. For monolayer culture, HGF, and HUVEC were grown in their complete media, α-MEM and EGM™-2, respectively. For co-culture experiments, two types of culture media were compared i.e. either both cells were grown in a 1:1 mix (by volume) of α-MEM and EGM™-2 or in α-MEM only. Then, cell morphology and proliferation were evaluated using inverted microscope (Carl Zeiss, Germany) to observe the growth of cells in both media.

CELL VIABILITY ASSAY

The 3,4,5-dimethylthiazol-2-yl-2,5-diphenyl tetrazolium bromide (MTT) assay was performed as previously described (Plumb et al. 1989) for evaluating the effect of growth factors on the viability of cells. Two separate culture conditions i.e. Group-A consisting of experiments performed with HGF in its complete growth medium (α-MEM) and in 1:1 medium containing α-MEM: EGM™-2 while Group-B was performed with HUVEC in its complete growth medium (EGM™-2) and in 1:1 medium containing α-MEM: EGM™-2, were tested. Briefly, HGFs and HUVECs were plated at a density of 5×10^3 cells in 96-well plates in complete medium as well as in co-culture medium (previously optimized) and allowed to adhere overnight. After 24 h, media were replaced by fresh media and cultures were exposed to different concentrations of FGF-2 and PDGF-BB (5, 10, 15, 20, 25, and 30 ng each). Cells treated with only basic growth medium served as a negative control. After 3 days, MTT assay (5 mg mL^{-1} in PBS) was performed as per standard procedures. Optical density (OD) was measured at a wavelength of 560∼750 nm.

CO-CULTURE OF HGF AND HUVEC IN TRANSWELL SYSTEM

Non-contacting co-culture system (Renaud & Martinoli 2016) was used to study the gene expression levels of fibroblast biomarkers (*Vimentin* (*VIM), Collagen type 1, alpha 1 (COL1A1),* and *Fibronectin (FN)*] and angiogenic biomarkers (*Cluster of differentiation-31* (*CD-31), Vascular endothelial cadherin (VE-CAD),* and *Von Willebrand factor* (*v-WF))* in the presence of growth factors. Briefly, prior to cell seeding, to promote cell attachment in a multiple well-plate and in ThinCert™ cell culture transwell inserts, recommended amount of culture medium was added and placed into the incubator at 37 ºC for 1 h. Next, HGFs (1×10^6 cells) were seeded in the multiple well-plate (6 well-plate; lower compartment) while HUVEC (1×10^6 cells) seeded on membrane transwell insert (upper compartment) and allowed to grow overnight. This is for initial equilibrium period for cell attachment. After 24 h of overnight incubation, the upper and the lower compartments were combined and growth factors (5 ng FGF-2 and 20 ng PDGF-BB) were added to initiate the experiment. Co-cultures were maintained for 72 h at 37 °C, 5% CO_2, and 95% humidity. Following that, the culture media were aspirated from both the compartments and cells from each group were harvested to quantify and isolate RNA for Real-Time PCR. Control group consisting of HGF only, HUVEC only, and HGF-HUVEC only, whereas HGF-HUVEC with growth factors were the treatment group.

RNA EXTRACTION AND REAL-TIME RT-PCR ANALYSIS

Total RNA was isolated from cells of all the groups and quantified by measuring the absorbance at 260 and 280 nm using Eppendorf BioPhotometer plus machine. One-Step real-time RT-PCR was performed to study the gene expression of fibroblast and angiogenic biomarkers using SensiFAST™ SYBR® Hi-ROX One-Step Kit exactly to the manufacturer's instructions. The mRNA expression level of *Glyceraldehyde 3-phosphate dehydrogenase* (*GAPDH)* was used as an endogenous control to normalize the data and the non-template control (NTC) was included in each experiment. The genes primer sequences were designed using NCBI Primer-Blast as shown in Table 1. The reactions were performed on the StepOnePlus™ Real Time PCR System (Applied Biosystems, USA) in MicroAmp™ Fast 8-Tube Strip, 0.1 mL (Applied Biosystems, USA) covered with MicroAmp® Optical 8-Cap Strips (Applied Biosystems, USA) manually set up in triplicates. PCR conditions were as follows: 45 °C for 10 min, 95 °C for 2 min followed by 40 cycles of 95 °C for 5 s (denaturation step), 60 °C for 10 s (annealing step) and 72 ºC for 5 s (extension step) during which fluorescence was measured. mRNA expression levels were recorded as threshold cycles (C_T). Data was acquired using the StepOnePlus™ Real Time PCR Software (Applied Biosystems, USA). After the real-time RT-PCR run, relative quantification was performed using the ΔΔCT method (Pfaffl 2001).

STATISTICAL ANALYSIS

The data are expressed as mean ± standard error of the mean (S.E.M). All experiments were done in triplicate. Statistical analysis for the cell viability assay was performed using one-way analysis of variance (ANOVA) for comparison between two means followed by Bonferroni post-hoc test, whereas, real-time RT-PCR data were processed by Kruskal Wallis test followed by Mann-Whitney U test for comparisons between groups using IBM SPSS software v 22.0 (SPSS, Chicago, IL, USA). All statistical analyses were performed at the significance level of $p < 0.05$.

Results and Discussion

OPTIMISATION OF HGF-HUVEC CO-CULTURE

The typical morphology of HGF showed spindle-shape and HUVEC showed a cobblestone-like shape as shown Figure 1. The co-culture medium was optimised prior to co-culture of HGF-HUVEC. For this, two sets of experiments were performed. In the first experiment, both cells were grown in a 1:1 mix (by volume) of α-MEM

and EGM™-2. The cells were observed and captured from day 1 until day 5 for HGF (Figure 2(A)-2(C)) and HUVEC (Figure 2(D)-2(F)). The results showed that both cells were grown in a 1:1 mix (by volume) of α-MEM and EGM™-2 maintained their characteristic morphology. Besides, the number of cells increased and reached confluency at the end of the experiment. In another set of experiment, HGF were maintained in EGM™-2 only and HUVEC in α-MEM only. The results showed that HGF proliferated in EGM™-2, however, although HUVEC did survive in α-MEM but could not proliferate.

In this study, the co-culture of HGF and HUVEC under specific culture conditions were focused. A prerequisite to a successful co-culture system is the use of a suitable culture medium, which fulfils the requirements of the co-cultured cell types. Previously, studies have been done on co-culture of ECs with different cell types and researchers have used different media. However, the selection of defined-media is still controversial. In the initial phase of this study, the optimisation of culture medium that would favour the co-culture of HUVEC-HGF was studied. For that, the monolayer culture was performed in their selected media which showed the typical morphology of HGF and HUVEC i.e. spindle-shaped and cobblestone shaped morphology, respectively. The characteristic morphology of these cells was in accordance with the previous studies on monolayer cultures (Bachetti & Morbidelli 2000; Mohd Nor et al. 2017).

This study showed that 1:1 mix (by volume) of fibroblast growth medium containing α-MEM and endothelial growth medium containing EGM™-2 is the best medium for the growth of HGF and HUVEC in co-culture. The use of this 1:1 mixture by volume of two media in this study was also in agreement with the previous studies which showed that under the effect of 1:1 mixture of two media, the cell proliferation, clustering of ECs, and angiogenic factor release was significantly observed (Cheung et al. 2015; Choong et al. 2006; Kolbe et al. 2011). In another set of experiment, HGF were maintained in EGM™-2 only and HUVEC in α-MEM only. The results showed that HGF grew in EGM™-2, however, HUVEC did survive in α-MEM but could not proliferate. The possible explanation to this observation that HUVEC could not proliferate in α-MEM alone is because this medium lacks some key ingredients of complete EGM™-2 media such as EGF, heparin, IGF-1 and FGF-2 which are necessary for enhancing EC proliferation (Kang et al. 1995).

EFFECT OF FGF-2 AND PDGF-BB ON THE PROLIFERATION OF HGF AND HUVEC

It has been shown that for Group A (HGF in α-MEM and HGF in α-MEM: EGM™-2) (Figure 3(A), 3(B)), the effect of FGF-2 was dose-dependent and the highest number of viable cells were seen at an optimum concentration of 5 ng mL^{-1}, whereas, for Group B (HUVEC in EGM™-2 and HUVEC in α-MEM: EGM™-2) (Figure 4(A), 4(B)), the effect of PDGF-BB was measured, and the most viable cells were seen at an optimum concentration of 20 ng mL^{-1}.

Fibroblast growth factor is a cellular growth factor that bind to heparin and heparin sulphate. MTT result of this study showed that the effect of FGF-2 on HGF is reported to be dose-dependent which is consistent with the previous studies (Nishimura & Terranova 1996; Palmon et al. 2000) in which local application of this growth factor on regeneration of periodontal tissues has been investigated and demonstrated that FGF-2 promotes the growth and proliferation of human PDL cells and exerts a dose-dependent effect on PDL and gingival fibroblast migration ($p<0.01$). Moreover, the effect of this growth factor has been studied on the proliferation and apoptosis of cultured HGF (Tanimoto et al. 2013) and the result has been in agreement with the stimulatory effects. In this study, the highest number of viable cells were seen at an optimum concentration of 5 ng mL^{-1} which is different with Walters et al. (2005), who performed a study to test the role of growth factors (FGF-2, PDGF, and TGF-β) on HGF minocycline uptake. Their study showed that both FGF-2 and PDGF at a concentration of 10 ng mL^{-1} significantly enhanced the minocycline uptake and the effect was reported to be dose-dependent.

PDGF-BB is a heparin-binding growth factor known to play a critical role in the maturation and remodelling of vessels during later stages of development and in angiogenesis (Minardi et al. 2017). Because endothelial proliferation is necessary for the formation of new vessels, angiogenic growth-regulatory molecules would be expected to induce mitogenesis in vascular ECs. In this study, it has been shown that the effect of PDGF-BB on HUVEC was not dose-dependent and that the most viable cells were seen at the optimum concentration of 20 ng mL^{-1}. Binding of PDGF to its receptors leads to activation of the receptor tyrosine kinase and to subsequent initiation of cytoplasmic signal transduction pathways, in turn leading to the migration, proliferation, and differentiation of PDGF-responsive cell types. Previously, growth response of PDGF-BB to HUVEC at the site of injury has been assessed (Zetter & Antoniades 1979). Their result showed that no significant increase in cell number or colony size was seen when HUVEC initially was seeded at a density of 1×10^4 cells. However, with the addition of 0.5 ng mL^{-1} PDGF-BB, a four-fold (4.8×10^4) increase in cell number was observed along with the increase in the colony size after 8 days that suggest the mitogenic activity of purified platelet mitogen (Zetter & Antoniades 1979). On the contrary, a dose-dependent effect of both PDGF-AB and -BB was also observed in a conventional two-dimensional culture where cell numbers were increased more by PDGF-BB and proved to be a potent mitogen. However, no effect on capillary EC

proliferation was seen even with higher concentrations (20 ng mL^{-1}) of PDGF-AB which demonstrated that this isoform has no mitogenic effect (Marx et al. 1994).

Of interest, bovine aortic ECs that displayed an 'angiogenic' phenotype in culture have PDGF-β receptors and respond to PDGF-BB was shown to form cords and tubes. Moreover, it has been shown that PDGF-BB at 1 ng mL^{-1} ($p<0.05$) and at 3 ng mL^{-1} or higher ($p<0.001$) dose-dependently increased DNA synthesis (Battegay et al. 1994). Shimizu et al. (1999) studied the effect of PDGF-BB on cultured chick cardiac myocytes and the results of viability assay showed that the effect of PDGF-BB was dose dependent and that the maximal mitogenic effect and increased DNA synthesis was achieved at 5 ng mL^{-1}. The results of these studies are not in agreement to our current findings on HUVEC where the effect was not dose-dependent. The possible explanation could be because of the phenotypically distinct cellular population (bovine aortic ECs, cardiac myocytes, and HUVEC) that are associated with differences in cell shape, spatial organisation, the nature of the substrate, and the ECM in the microenvironment. However, in general, the stimulatory effects of PDGF-BB, irrespective of the type of ECs and cellular activity are corroborated with present study and are thought to be suggestive of the angiogenic response with HUVEC in the culture.

EFFECT OF FGF-2 AND PDGF-BB ON GENE EXPRESSION OF FIBROBLAST AND ANGIOGENIC BIOMARKERS IN HGF AND HUVEC

The expression level of each gene was measured, and normalized to *GAPDH* expression. The Kruskal Wallis test for fibroblast and angiogenic gene biomarkers of the treatment group (with growth factors) showed significant changes in expression level ($p < 0.05$) after three days of co-culture experiment compared to control group(s) in which genes were slightly expressed but not significant ($p > 0.05$) (Figure 5(A)-5(F)). Results showed that the r^2 and percentage (%) of *VIM, COL1A1, FN, CD31, VE-Cadherin,* and *vWF* are 0.989, 95.92%; 0.99, 99.36%; 0.996, 109.42%; 0.978, 97.29%; 0.988, 95.60%; 0.991, 95.02%, respectively.

VIM, COL1A1, and FN are fibrous proteins that are the major component of ECM secreted by fibroblasts. Usually, expression of these proteins is linked to support and facilitate cellular attachment and communication by activating signalling pathways (Albelda & Buck 1990; Manimegalai et al. 2016). On the other hand, *CD-31, VE-Cad,* and *v-WF* are commonly known as vascular endothelial cell specific markers which are majorly involved in vascular biology and angiogenesis (Goncharov et al. 2017). In this study, the expression of these biomarkers was significantly observed in a co-cultured group with the addition of optimised concentration of GFs (FGF-2 and PDGF-BB) when compared to control. Previously, studies have been done on the synergistic role of these two angiogenic growth factors in a combination to study the vascular stability and angiogenesis (Cao et al. 2003; Li et al. 2010; Nissen et al. 2007; Sufen et al. 2011). It has been confirmed that the establishment of the functional vascular network requires the addition of more than one angiogenic factor. The expression of these genes in the presence of FGF-2 and PDGF-BB in a co-culture of HGF and HUVEC could be because of the synergistic role of these two growth factors. The underlying mechanism may be complex, but it is believed that addition of FGF-2 upregulates the PDGFR-α and PDGFR-β which activates PDGF receptor-transduced signalling pathways leading to more pronounced cellular interactions in a co-culture environment (Cao et al. 2003).

TABLE 1. Sequences of the primers used for One-Step real-time RT-PCR of fibroblast and angiogenic biomarkers

Gene	Primer sequences 5′ to 3′	Accession no.	Amplicon size (bp)
FN	CGGAGAGACAGGAGGAAATAGCCCT	NM_001306132	150
	TTGCTGCTTGCGGGGCTGTC		
COL1A1	TACAGCGTCACTGTCGATGGC	NM_000088	61
	TCAATCACTGTCTTGCCCCAG		
VIM	CCTTGAACGCAAAGTGGAATCT	M14144	119
	CCACATCGATTTGGACATGCT		
v-WF	GAATGGTGCTGTACGGCTGG	NM_000552	57
	CACGCATCGCTCCTGACAC		
CD-31	TCTAGAACGGAAGGCTCCCT	NM_001101655	145
	TGGGAGCAGGGCAGGTTCA		

VE-CAD	AGAAGAAGCCTCTGATTGG TGTGACTCGGAAGAACTG	NM_001795	113
GAPDH	CAACAGCGACACCCACTCCT CACCCTGTTGCTGTAGCCAAA	NM_002046	115

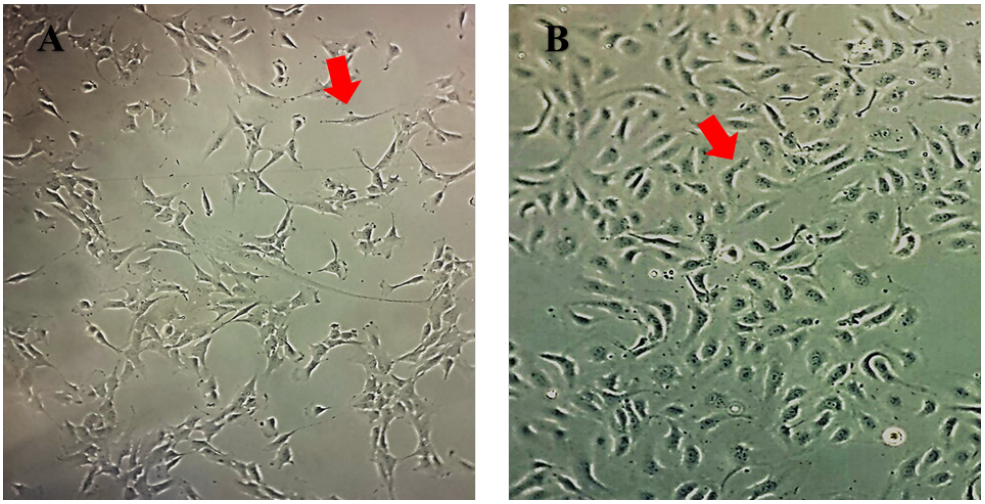


FIGURE 1. Typical morphology of HGF and HUVEC in a monolayer culture. Arrows in red showing; A. Spindle-shaped morphology of HGF, and B. Cobblestone-like shape of HUVEC

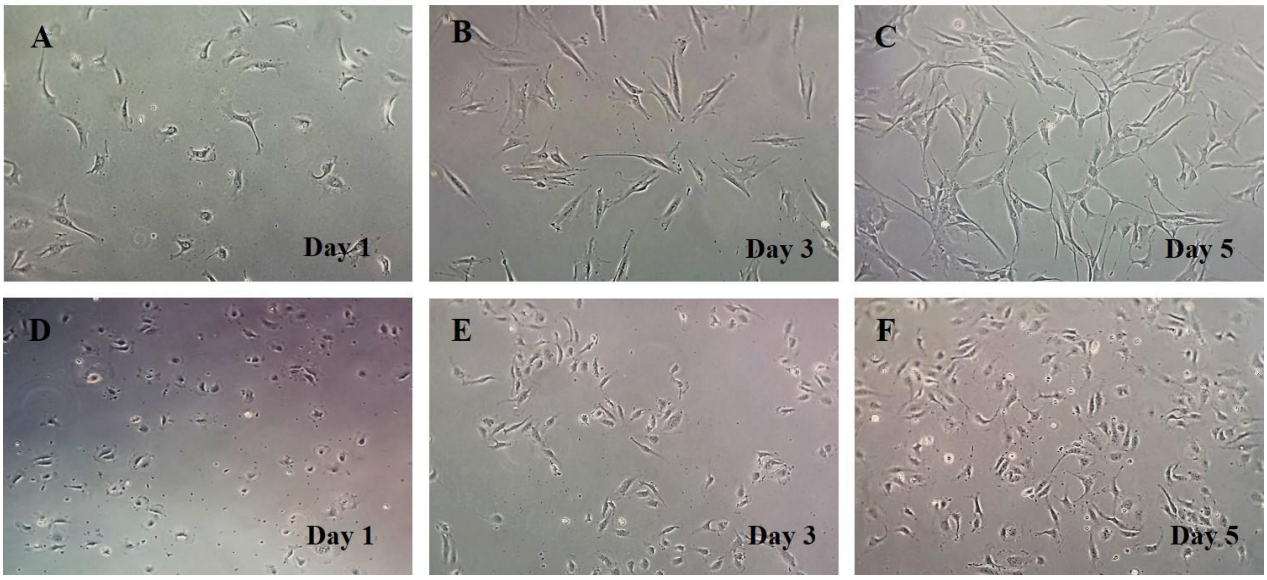


FIGURE 2. Images of HGF and HUVEC morphology in 1:1 mix (by volume) of α-MEM and EGM™-2 at day 1 until 5 using an inverted microscope. A-C. HGF proliferated and maintained its spindle shaped morphology, and D-F. HUVEC proliferated and maintained its cobblestone-like shape (magnification: × 100)

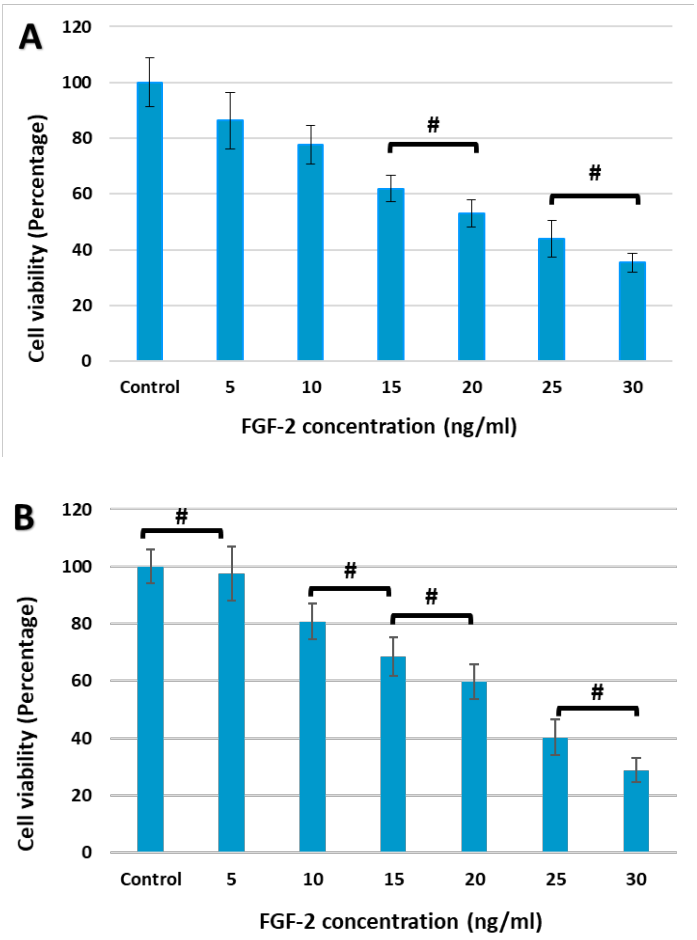
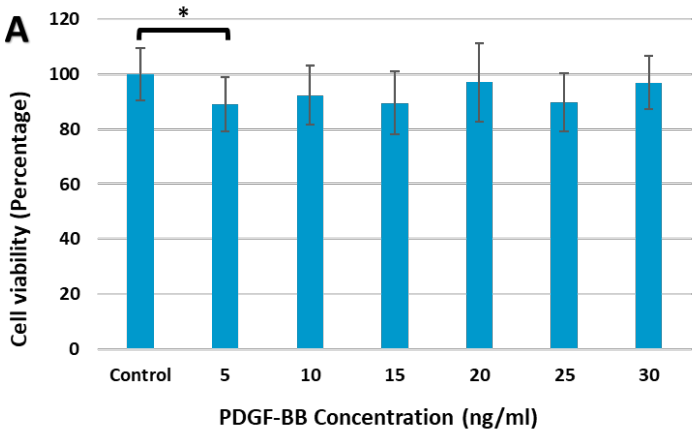


FIGURE 3. Effect of FGF-2 on the viability of HGFs based on MTT assay. A. Effect of various concentration of FGF-2 on HGF in growth medium containing α-MEM, and B. Effect of various concentration of FGF-2 on HGF in growth medium containing 1:1 mix (by volume) of α-MEM and EGM™-2. The values of OD of the different concentrations were normalised to the average OD value of the control group. Data are presented as mean ± S.E.M., # indicates a non-significant difference ($p > 0.05$) between the groups. Other pairs are significant



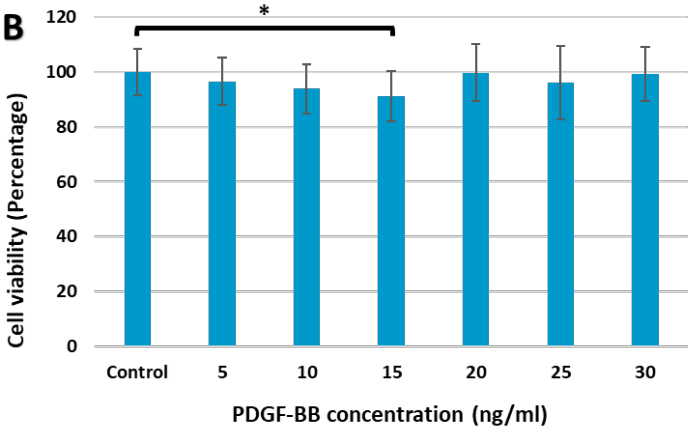


FIGURE 4. Effect of PDGF-BB on the viability of HUVECs based on MTT assay. A. Effect of various concentration of PDGF-BB on HUVEC in growth medium containing EGM™-2, and B. Effect of various concentration of PDGF-BB on HUVEC in growth medium containing 1:1 mix (by volume) of α-MEM and EGM™-2. The values of OD of the different concentrations were normalised to the average OD value of the control group. Data are presented as mean ± S.E.M., * indicates a significant difference ($p < 0.05$) between the groups

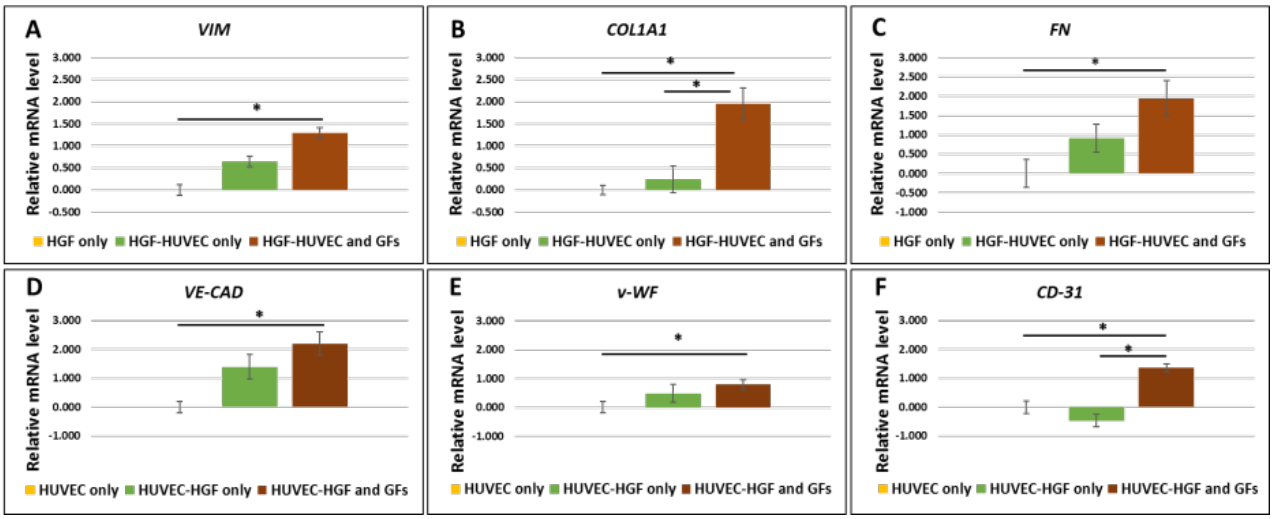


FIGURE 5. Gene expression levels of fibroblast and angiogenic biomarkers using real-time RT-PCR. The graphs represent the relative mRNA gene expression levels of biomarkers; A. *VIM,* B. *COL1A1,* C. *FN,* D. *VE-CAD,* E. *v-WF,* and F. *CD-31*. The mRNA level of each gene biomarker in a co-cultured group in the presence of growth factors (FGF-2 and PDGF-BB) showed significant expression. The data are represented as the mean ± S.E.M, * indicates a significant difference ($p < 0.05$) between the groups

CONCLUSION

Together, data from our study conclude the importance of using co-culture approach for studying the cellular behaviour of heterotypic cell population. Co-culture of HGF and HUVEC plays a significant role in the expression of fibroblastic and angiogenic genes, however addition of FGF-2 and PDGF-BB in the co-culture further enhanced these effects. These findings supported the important role of these growth factor in angiogenic activity which need to be further explored in the co-culture system. As vascularisation in tissue engineered constructs for treating gingival recession is essential, further investigations could

be carried out using this co-culture method with the present of these growth factors for better understanding the cellular interactions between HGF and HUVEC.

ACKNOWLEDGEMENTS

The authors thank the staff members of Craniofacial Science Laboratory, USM. This work was supported by Universiti Sains Malaysia Research University Grant (1001/PPSG/812168) and USM Bridging Grant (304/PPSG/6316168).

REFERENCES

Albelda, S.M. & Buck, C.A. 1990. Integrins and other cell adhesion molecules. *FASEB J.* 4(11) :2868-2880.

Bachetti, T. & Morbidelli, L. 2000. Endothelial cells in culture: A model for studying vascular functions. *Pharmacol. Res.* 42(1): 9-19.

Battegay, E.J., Rupp, J., Iruela-Arispe, L., Sage, E.H. & Pech, M. 1994. PDGF-BB modulates endothelial proliferation and angiogenesis *in vitro* via PDGF beta-receptors. *J. Cell Biol.* 125(4): 917-928.

Cao, R., Brakenhielm, E., Pawliuk, R., Wariaro, D., Post, M.J., Wahlberg, E., Leboulch, P. & Cao, Y. 2003. Angiogenic synergism, vascular stability and improvement of hind-limb ischemia by a combination of PDGF-BB and FGF-2. *Nat. Med.* 9(5): 604-613.

Cheung, J.W., Jain, D., McCulloch, C.A. & Santerre, J.P. 2015. Pro-angiogenic character of endothelial cells and gingival fibroblasts cocultures in perfused degradable polyurethane scaffolds. *Tissue Eng. Part A* 21(9-10): 1587-1599.

Choong, C.S., Hutmacher, D.W. & Triffitt, J.T. 2006. Co-culture of bone marrow fibroblasts and endothelial cells on modified polycaprolactone substrates for enhanced potentials in bone tissue engineering. *Tissue Eng.* 12(9): 2521-2531.

Costa-Almeida, R., Gomez-Lazaro, M., Ramalho, C., Granja, P.L., Soares, R. & Guerreiro, S.G. 2015. Fibroblast-endothelial partners for vascularization strategies in tissue engineering. *Tissue Eng. Part A* 21(5-6): 1055-1065.

Gallagher, S.I. & Matthews, D.C. 2017. Acellular dermal matrix and subepithelial connective tissue grafts for root coverage: A systematic review. *J. Indian Soc. Periodontol.* 21(6): 439-448.

Goncharov, N.V., Nadeev, A.D., Jenkins, R.O. & Avdonin, P.V. 2017. Markers and biomarkers of endothelium: When something is rotten in the state. *Oxid. Med. Cell Longev.* 2017: Article ID. 9759735.

Jati, A.S., Furquim, L.Z. & Consolaro, A. 2016. Gingival recession: Its causes and types, and the importance of orthodontic treatment. *Dental Press J. Orthod.* 21(3): 18-29.

Kang, S.S., Gosselin, C., Ren, D. & Greisler, H.P. 1995. Selective stimulation of endothelial cell proliferation with inhibition of smooth muscle cell proliferation by fibroblast growth factor-1 plus heparin delivered from fibrin glue suspensions. *Surgery* 118(2): 280-287.

Kolbe, M., Xiang, Z., Dohle, E., Tonak, M., Kirkpatrick, C.J. & Fuchs, S. 2011. Paracrine effects influenced by cell culture medium and consequences on microvessel-like structures in cocultures of mesenchymal stem cells and outgrowth endothelial cells. *Tissue Eng. Part A* 17(17-18): 2199-2212.

Li, J., Wei, Y., Liu, K., Yuan, C., Tang, Y.J., Quan, Q.L., Chen, P., Wang, W., Hu, H. & Yang, L. 2010. Synergistic effects of FGF-2 and PDGF-BB on angiogenesis and muscle regeneration in rabbit hindlimb ischemia model. *Microvasc. Res.* 80(1): 10-17.

Manimegalai, A, Rao, S. & Ravindran, D. 2016. Fibronectin in periodontal health and disease. *J. Orofac. Sci.* 8(1): 12-15.

Marx, M., Perlmutter, R.A. & Madri, J.A. 1994. Modulation of platelet-derived growth factor receptor expression in microvascular endothelial cells during *in vitro* angiogenesis. *J. Clin. Invest.* 93(1): 131-139.

Minardi, S., Pandolfi, L., Taraballi, F., Wang, X., De Rosa, E., Mills, Z.D., Liu, X., Ferrari, M. & Tasciotti, E. 2017. Enhancing vascularization through the controlled release of platelet-derived growth factor-BB. *ACS Appl. Mater. Interfaces* 9(17): 14566-14575.

Mohd Nor, N.H., Berahim, Z., Azlina, A., Mokhtar, K.I. & Kannan, T.P. 2017. Identification and characterization of intraoral and dermal fibroblasts revisited. *Curr. Stem Cell Res. Ther.* 12(8): 675-681.

Moraschini, V. & Barboza Edos, S. 2016. Use of platelet-rich fibrin membrane in the treatment of gingival recession: A systematic review and meta-analysis. *J. Periodontol.* 87(3): 281-290.

Nishimura, F. &Terranova, V.P. 1996. Comparative study of the chemotactic responses of periodontal ligament cells and gingival fibroblasts to polypeptide growth factors. *J. Dent. Res.* 75(4): 986-992.

Nissen, L.J., Cao, R., Hedlund, E.M., Wang, Z., Zhao, X., Wetterskog, D., Funa, K., Brakenhielm, E. & Cao, Y. 2007. Angiogenic factors FGF2 and PDGF-BB synergistically promote murine tumor neovascularization and metastasis. *J. Clin. Invest.* 117(10): 2766-2777.

Palmon, A., Roos, H., Edel, J., Zax, B., Savion, N., Grosskop, A. & Pitaru, S. 2000. Inverse dose- and time-dependent effect of basic fibroblast growth factor on the gene expression of collagen type I and matrix metalloproteinase-1 by periodontal ligament cells in culture. *J. Periodontol.* 71(6): 974-980.

Pfaffl, M.W. 2001. A new mathematical model for relative quantification in real-time RT-PCR. *Nucleic Acids Res.* 29(9): e45.

Plumb, J.A., Milroy, R. & Kaye, S.B. 1989. Effects of the pH dependence of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-tetrazolium bromide-formazan absorption on chemosensitivity determined by a novel tetrazolium-based assay. *Cancer Res.* 49(16): 4435-4440.

Renaud, J. & Martinoli, M.G. 2016. Development of an insert co-culture system of two cellular types in the absence of cell-cell contact. *J. Vis. Exp.* doi: 10.3791/54356.

Shimizu, T., Kinugawa, K., Yao, A., Sugishita, Y., Sugishita, K., Harada, K., Matsui, H., Kohmoto, O., Serizawa, T. & Takahashi, T. 1999. Platelet-derived growth factor induces cellular growth in cultured chick ventricular myocytes 1. *Cardiovasc. Res.* 41(3): 641-653.

Shkreta, M., Atanasovska-Stojanovska, A., Dollaku, B. & Belazelkoska, Z. 2018. Exploring the gingival recession surgical treatment modalities: A literature review. *Open Access Maced. J. Med. Sci.* 6(4): 698-708.

Song, H.G., Rumma, R.T., Ozaki, C.K., Edelman, E.R. & Chen, C.S. 2018. Vascular tissue engineering: Progress, challenges, and clinical promise. *Cell Stem Cell* 22(3): 340-354.

Sufen, G., Xianghong, Y., Yongxia, C. & Qian, P. 2011. bFGF and PDGF-BB have a synergistic effect on the proliferation,

migration and VEGF release of endothelial progenitor cells. *Cell Biol. Int.* 35(5): 545-551.

Tanimoto, K., Ohkuma, S., Tanne, Y., Kunimatsu, R., Hirose, N., Mitsuyoshi, T., Yoshimi, Y., Su, S. & Tanne, K. 2013. Effects of bFGF on the modulation of apoptosis in gingival fibroblasts with different host ages. *Int. J. Dent.* 2013: Article ID. 619580. .

Traore, M.A. & George, S.C. 2017. Tissue engineering the vascular tree. *Tissue Eng. Part B Rev.* 23(6): 505-514.

Um Min Allah, N., Berahim, Z., Ahmad, A. & Kannan, T.P. 2017. Biological interaction between human gingival fibroblasts and vascular endothelial cells for angiogenesis: A co-culture perspective. *Tissue Eng. Regen. Med.* 14(5): 495-505.

Walters, J.D., Nakkula, R.J. & Maney, P. 2005. Modulation of gingival fibroblast minocycline accumulation by biological mediators. *J. Dent. Res.* 84(4): 320-323.

Zetter, B.R. & Antoniades, H.N. 1979. Stimulation of human vascular endothelial cell growth by a platelet-derived growth factor and thrombin. *J. Supramol. Struct.* 11(3): 361-370.

Zuhr, O., Baumer, D. & Hurzeler, M. 2014. The addition of soft tissue replacement grafts in plastic periodontal and implant surgery: Critical elements in design and execution. *J. Clin. Periodontol.* 41(Suppl 15): S123-S142.

Nasar Um Min Allah, Zurairah Berahim*, Azlina Ahmad & Kannan Thirumulu Ponnuraj
School of Dental Sciences
Universiti Sains Malaysia
16150, Kubang Kerian, Kelantan Darul Naim
Malaysia

Kannan Thirumulu Ponnuraj
Human Genome Centre
School of Medical Sciences
Universiti Sains Malaysia
16150, Kubang Kerian, Kelantan Darul Naim
Malaysia

*Corresponding author; email: zurairah@usm.my

Received: 2 October 2019
Accepted: 27 March 2020