Original Research Article

AN EXPERIMENTAL MODEL OF HEPATIC STEATOSIS TO DETECT LIPID ACCUMULATION

Abstract

Obesity is associated with an increased risk of metabolic syndromes such as type 2 diabetes, insulin resistance, dyslipidaemia and non-alcoholic fatty liver disease. Obesity occurs as a result of an imbalance between food intake and energy expenditure leading to excessive accumulation of adipose tissue**.** NAFLD is the most common liver condition and related to the resistance of insulin. Insulin resistance is associated with an increased influx of lipid into the liver promoting accumulation of hepatic triglyceride. This study aims to develop an experimental model of hepatic steatosis with lipid over-accumulation. HepG2 cells were cultured for 24 hours in free fatty acid media (1:2 palmitic acid and oleic acid respectively). Intracellular lipid content and lipotoxicity were determined by oil red O staining followed by colorimetric detection. This experiment was accomplished by defining the experimental conditions of lipid exposure that leads to significant intracellular fat accumulation in the absence of lipotoxicity with 1 mM of free fatty acid media. As a result, oleic and palmitic acids could be over-accumulated in HepG2 cells. 1 mM free fatty acid media did not affect the cell integrity and did not cause lipotoxicity of the cells.

Keywords*: *hepatocellular carcinoma (HepG2) cells, fat accumulation, Oil Red O, Nile Red, lipotoxicity, …

1. INTRODUCTION

Increased incidence of obesity is reaching epidemic proportions because of lifestyle modification especially change in eating habits. Obesity complications including type 2 diabetes, cardiovascular diseases, metabolic disorders and many types of cancer [1] have raised a significant health concern in the world especially in developed countries [2,3]. Therefore, many studies of molecules regulating the development of obesity and its associated pathologies are ongoing to treat and prevent obesity [4]. An important link between obesity, hypertension and sympathetic nerve activity (SNA) is leptin [5]. Leptin is a 16 kDa protein produced by adipocytes and controls body weight by regulating appetite and energy expenditure [6,7]. The absence of functional leptin receptors or deficiency in leptin is related with distinct hyperphagia and reduced energy expenditure [8], whereas viral vectors increase leptin by overexpression of leptin gene or infusion of leptin, this lead to decrease food intake and increases the expenditure of energy [9,10]. Leptin (adipocyte hormone) increases with increase proportion to adipose tissue mass and decrease with weight loss [11]

and plays a key role in glucose homeostasis facilitated by its direct action on the central nervous system [12]. Glucose is an essential nutrient and source of energy whose homeostasis is important to maintain proper cell functions, since the physiology of the body can be weakened by either hypoglycaemia or hyperglycaemia leading to cell death. The inability of the cells to use or take up glucose as an energy source upon stimulation by insulin is defined as insulin resistance (IR) [13]. Binding of insulin induces the intrinsic protein tyrosine kinase activity to its receptor; the tyrosine residues are phosphorylated in the insulin receptor as a result of activating intrinsic protein tyrosine kinase activity this is the first step. "*Subsequent steps involved the activation of the heterodimeric p85/p110-PI3K complex including generation of the lipid second messenger PIP3 (Phosphatidylinositol (3, 4, 5)-trisphosphate) which activates PDPK1 (phosphoinositide-dependent protein kinase-1), PKB/Akt (Protein Kinase B) and a typical PKC isoform and recruitment of adapter molecule's insulin receptor substrates (IRS), IRS1 and IRS2"* [14,15].

The most common form of the chronic liver disease is a non-alcoholic fatty liver disease (NAFLD), its prevalence increase with an increased incidence of obesity [1,16]. NAFLD is defined as the excess accumulation of fat in the liver that is not a result of alcohol consumption, genetic disorders or drug use [17]. The accumulation of lipids in micro and macro vesicles in more than 5 % hepatocytes, mostly in the perivenular hepatocytes is known as Non-alcoholic steatohepatitis (NASH). NASH associated with steatosis and necro-inflamation is a more severe form of NAFLD and may lead to hepatic fibrosis and cirrhosis [18]. Progression of simple steatosis to NASH is contributed by increased delivery of fatty acids to the liver. Fatty acids such as palmitic and oleic acid are found in triacyl-sn-glycerols of seed oils and animal depot fats in our daily diet. Palmitic acid is a saturated fatty acid that induces apoptosis in hepatocytes [19]. In the presence of oleic acid, the palmitate-induced apoptosis is reduced [19]. It is known that lipid accumulation in NASH is induced by free fatty acids (FFA) [20]. To study NAFLD, HepG2 cells have been widely used. HepG2 cells are derived from tumor cells; thus they behave differently from normal cells [21]. Lipotoxicity - a metabolic syndrome caused by the accumulation of free fatty acids in non-adipose tissue can lead to cellular dysfunction and eventually inevitable death [22]. Triglycerides are the major lipid stored in NAFLD recent data suggest that triglyceride accumulation may be hepatoprotective in the liver. A diacylglycerol acyltransferase 1 or 2 catalyze the synthesis of hepatic triglyceride [23]. Accumulation of FFA is likely to have toxic effects in hepatocytes in contrast to triglyceride. The study of Li et al. (2009) demonstrates the main determinant of hepatocellular damaged in NAFLD is the ratio of monounsaturated FAs (MUFA) to saturated FAs (SFA) [24].

Protein tyrosine phosphatases (PTPs) have been involved in the modulation of glucose homeostasis *in vivo*, including protein tyrosine phosphatase 1B (PTP1B) [25]. The IR PTK in liver and muscle is dephosphorylated by PTP1B to regulate glucose homeostasis. Increasing the expression of PTP1B leads to insulin resistance in people and rodents and knockout of PTP1B is associated with leanness and insulin sensitivity in rodents, this suggests that PTP1B is an important molecular target for the treatment of diabetes and obesity. Due to the role of

PTP1B in IR and after leptin signalling, PTP1B can be used as a target for the development of therapeutics for the treatment of obesity and type 2 diabetes. Antisense oligonucleotides that target PTP1B are in clinical trials whereas drugs inhibiting the activity of PTP1B are in preclinical development [26]. Decreasing the level of PTP1B in peripheral tissues is associated with improved insulin sensitivity, regulates hyperglycaemia and reduced obesity in these mice [27]. This suggests that PTP1B plays a vital role in the regulation of body mass in one or more peripheral tissues independent of effects in the brain [27]. A typical model to study hepatic steatosis is FFA induced lipid accumulation in hepatocytes [28]. This study aims to develop an experimental model of hepatic steatosis using HepG2 cell line and test the lipid accumulation in liver cells in the designed model. To achieve the aim, the study used Oil red O and Nile red staining to measure lipid levels in HepG2 cell lines.

2. MATERIALS AND METHODS

2.1. Materials

Human hepatocellular carcinoma (HepG2) cells were supplied by Sheffield Hallam University. Cells were grown in high glucose (4.5 g/L) Dulbecco's modified Eagle's medium with ultra-glutamine (DMEM) (Lonza, UK), 10 % Fecal Calf Serum (FCS) (Gibco, UK) and 1 % penicillin/streptomycin (Lonza, UK).

Basic culture media was prepared with 200 ml of DMEM (Lonza, UK), 2 ml 1 % penicillin/streptomycin (Lonza, UK) and 2 g of 1 % Bovine Serum Albumin (BSA) (Thermo-Fisher).

Oleic acid (Sigma-Aldrich) and palmitic acid (Sigma-Aldrich) dissolved in dimethyl sulfoxide were diluted in basic media to obtain 30 mM of free fatty acid (FFA) media (stock solution). This stock solution was further diluted with basic culture media to obtain 1 mM FFA media.

2.2. Oil red O colorimetric assay

A stock solution of Oil red O (ORO) was prepared by dissolving 0.7 g of ORO in 200 ml of Isopropyl alcohol. Bakers' formalin was prepared by adding 10 ml of 37 % formaldehyde and 10 ml of 10 % (w/v) calcium chloride solution to 80 ml of water and stored at 4°C. To prepare glycerol gelatine, 5 g gelatine was gently mixed with 50 ml glycerol in 50 ml water at 50ºC, and stored at 4ºC, then heating at 55-60ºC before use.

Cells were seeded in 12-well plate for 24 hours before treatment with 1 mM fatty acid at a density of 50000 cells per well. A half of the plate (6 wells) was used as control samples and the other half was treated with 1 mM of FFA and incubated for 24 hours at 37ºC and 5 % CO_2, in SANYO incubator before staining with Oil red O.

A 60 % ORO solution was prepared by diluting stock ORO with water at 3:2 ratio. Harris haematoxylin (Sigma Aldrich, UK) and 60 % ORO were filtered before use. Treatment and basic media were removed from each well and cells were washed 2 times in Hanks Balanced Salt solution (Sigma Aldrich, UK), the excess was poured off and blotted with a dry tissue.

Each well was fixed with 780 µl of bakers' formalin at 4ºC for 30 minutes, the excess was poured off and blotted with a dry tissue. 780 µl of 60 % ORO was added to each well and left to incubate for 10 minutes at room temperature. Cells were rinsed with water for 5 minutes after staining. Excessive water was blotted with dry tissue before staining cells with 780 µl of Harris haematoxylin and incubated for 2 minutes at room temperature. Cells were rinsed with water for 5 minutes. Excessive water was blotted with a dry tissue and 2 drops of glycerol gelatine were added to each well. Stained cells were observed under x400 magnification of the microscope and quantified using Image J program. The threshold was set at 163 and 213 for minimum and maximum, respectively.

2.3. Proliferation Assay

100x stock solution of Alamar blue (Sigma-Aldrich, UK) was prepared by dissolving 1 mg Alamar blue in 1 ml of 1x PBS. Working concentration was achieved by diluting 30 µl of 100x stock solution in 30 ml of basic media. To measure cell proliferation, negative control was achieved by adding 1 ml of 1 % Triton X-100 solution to each control and treated sample, then incubated for 1 hours before staining with Alamar Blue. After incubation of the negative control, all cell media was removed and 2 ml of Alamar blue solution was added followed by a 4-hour and 20-hour incubations at 37ºC and 5 % CO_2, in SANYO incubator. Absorbance was measured at 570 nm using GENESYS 10S UV-VIS (Thermo-Fisher) after 4 and 20 incubation hours.

2.4. Protein quantification

Cells were seeded in a 6-well plate for 24 hours before treatment with 1 mM fatty acid at a seeding density of 50000 cells per well. Cells were incubated at 37 ºC and 5 % CO_2, in SANYO incubator. Half (3) of the plate was used as control wells and the other half was treated with 1 mM FFA for 24 hr at 37ºC and 5 % CO_2, in SANYO incubator. Bradford reagent was prepared by dissolving 50 mg Coomassie brilliant blue in 24 ml 99 % ethanol; 50 ml of 85 % (w/v) phosphoric acid was added and diluted to a final volume of 500 ml with water, this solution was filtered before use. Protein standard was made by dissolving 0.05 g BSA in 50 ml warm water at a concentration of 1000 µg/ml. A serial dilution was prepared in the following concentrations of 1000, 500, 250, 125, 63, 31 and 0 µg/ml.

After treatment, basic media was removed from each well and cells were washed with 1x PBS. 20 µl of cell lytic M reagent was added to each well and incubated at room temperature for 15 minutes on a shaker. Lysed cells were collected by scraping. The lysed cells were centrifuged for 15 minutes at 12000 x g at room temperature. The supernatants were removed and the pellets were re-suspended in 100 µl of water. Each pellet and supernatant sample were diluted 1:10 with water, 10 µl was pipetted in triplicate into a flat bottomed 96-well plate. Standards were also added to the plate in duplicate. 200 µl of Bradford reagent was added into each well and absorbance was measured by MULTISCAN FC; Thermo-Fisher, UK at 595 nm.

2.5. Nile Red fluorescence assay

Cells were seeded in a 6-well plate for 24 hours before treatment with 1 mM fatty acid at a seeding density of 50000 cells per well. Cells were incubated at 37ºC and 5 % CO_2, in SANYO incubator. The half (3 wells) of each plate was used as control wells and the other half was treated with 1 mM concentration for 24 hours at 37ºC and 5 % CO_2, in SANYO incubator. Working solution of Nile Red (1 µg/ml) was achieved by diluting 1 mg in 1 ml methanol before diluting 5 µl with 5 ml 1x PBS.

Cells were washed with 500 µl of PBS (Lonza, UK). 250 µL of trypsin was added to each well and placed in an incubator for 5 min for the cells to dislodge. 250 µl of media was added to each well and pipetted into different tubes. Cells were centrifuged at 500 x g for 5 minutes. Supernatants were discarded and pellets were re-suspended in 1.5 ml 1xPBS and centrifuged at 500 x g for 5 minutes. 500 µl of 1x Nile Red in PBS was added and incubated for 5 minutes on ice. Cells were washed in 1.5 ml PBS, supernatant was discarded and pellet was re-suspended in 500 µl of PBS. Nile red fluorescence was determined by flow cytometry with Becton Dickinson FACS Calibur System, FL2 emission channel, at excitation wavelength of 488 nm and emission wavelength of 550 nm.

3. RESULTS

3.1. Oil red O colorimetric assay

After 24-hour incubation with 1 mM of FFA media in a 12-well plate, cells were stained with Oil red O to observe the accumulation of lipid (palmitic acid and oleic acid) at x400 magnification of the microscope. Compared with the control samples, the appearance of red spots in Figure 1B shows lipid accumulation in FFA-treated HepG2 cells. The quantification of stained HepG2 cells using Image J is expressed as % average areas of 6 wells. In control cells, the percentage area was approximately 12% while that was nearly 16% in treated cells.

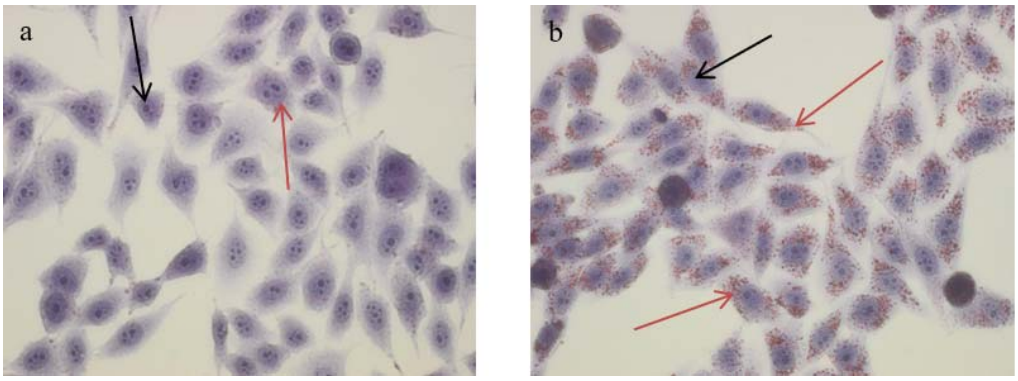

Figure 1. Oil Red O staining of HepG2 cells in
A) control samples, B) FFA-treated HepG2 cells samples
** red arrow shows lipid droplet; black arrow shows cell nucleus*

3.2 Proliferation Assay

Proliferation assay was used to monitor the response and health of HepG2 cells in culture after treatment with 1 mM FFA. The assay shows the lipotoxicity of HepG2 cells. Treatment

of HepG2 cells with 1 mM of FFA media did not significantly decrease the cell viability, compared to control cells. At the beginning point, the reduction of Alamar blue calculated was low, under 5% in both control and treated cells. After incubation, this number increased following the increase in incubation time. After incubation in 4 hours, the amount of Alamar blue that was reduced in both samples was 17 %. This proportion reached 52 % and 57 % for control and treated cells, respectively after 20-hour incubation. The cell growth inhibition was difference in treated and control HepG2 cells. After incubating these cells in 4 hours, the difference percentage was 95 % and increased up to 112 % after 20-hour incubation.

The amount of protein has been successfully measured in HepG2 cells. In the standard curve, the absorbance increased when increasing the concentration of protein from 0 to 31, 63, 125, 250, 500 and 1000 µg/ml. The regression equation was A = 0.0012C + 0.2698 with the (R^2 = 0.9962). Table 1 shows the difference in concentration of proteins extracted from pellet and suspension of the samples, and difference between untreated and treated cells. High protein concentrations were seen in the suspension of both the control and treated cells, 1.98±0.11 and 1.55±0.33, respectively. The pellet of cells had low protein concentrations. Treated cells contained high protein concentration in pellet but low protein concentration in suspension compared to control cells.

Table 1. Concentration of protein calculated from the standard curve

Samples		Protein concentration (µg/ml) in triplicate			Mean of protein concentration (µg/ml)
Control cells	pellet	0.54	0.51	0.45	0.5±0.04
	suspension	2.01	2.09	1.83	1.98±0.11
Treated cells	pellet	0.62	0.81	0.59	0.67±0.10
	suspension	1.69	1.87	1.09	1.55±0.33

3.3. Nile red fluorescence assay

The content of intracellular lipid droplets was determined by Nile red staining and the cellular FFA uptake was quantified by flow cytometric assay. Cells exposed to 1 mM FFA for 24 hours induced fat accumulation. Unstained control cells (figure 2A) were used to adjust the settings of the flow cytometer to measure intensity of unstained treated cells. This procedure is similar to measure intensity of stained treated cells. Unstained cells gave very low signals as compared with stained cells. For example, unstained treated cells gave only 2.75 while stained treated cell gave up to 6130 intensity unit. Compared to stained control cells (figure 2G) which caused only 1366 intensity, the fluorescence signal of lipid in the stained treated cells was evidently higher, up to roundly 6130 intensity unit (figure 2H). In summary, the difference in fluorescence intensity shows an increase in intracellular lipid in cells treated with FFA media.

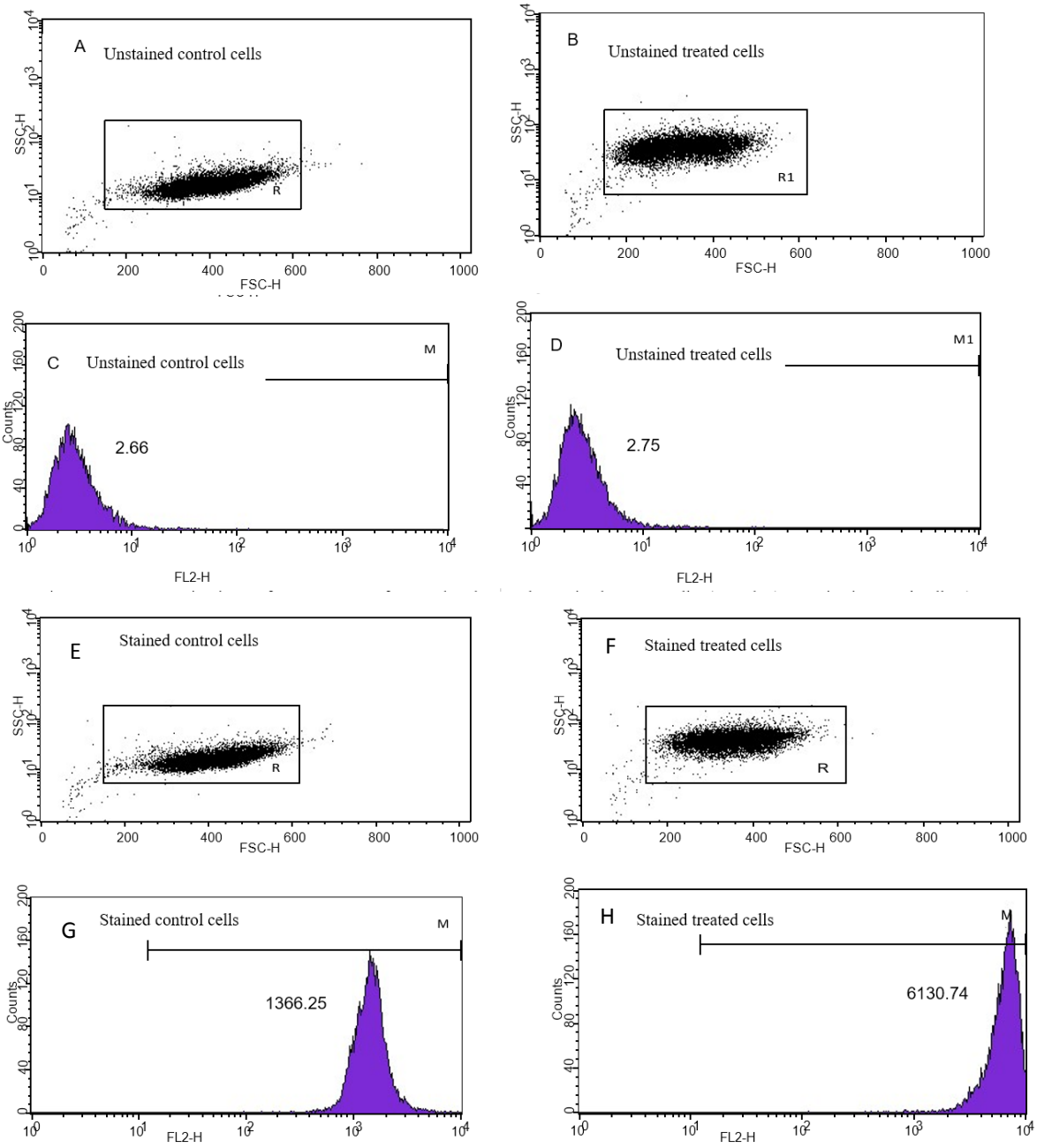

Figure 2. Fluorescent intensity of unstained, stained control and treated HepG2 cells
A and C) Unstained control cells; B and D) Unstained treated cells with 1 mM FFA media
E and F) Stained control cells; G and H) stained treated cells with 1 mM FFA media

DISCUSSION

NAFLD causes chronic liver disease and prevalent increase with growing epidemic of obesity worldwide. The prevalent impact of NAFLD on the growing epidemic of obesity make NAFLD has become the most common cause of liver disease [29]. NAFLD is associated with several non-hepatic related complications and has the potential to develop hepatic fibrosis and end-stage liver disease [30]. There is a general understanding that patients with NASH have increased lipolysis, and subsequently, a high circulating FFA level, accumulation of

lipid in liver cells is contributed by the increase in FFA inflow and de novo lipid synthesis [31]. A model for investigating NASH that is usually used is incubating hepatocytes with FFA [28]. The structure of fatty acids affects their activity biologically, and they are classified as saturated and unsaturated fatty acids. The saturated FAs induce lipotoxicity, insulin resistance and apoptosis. A saturated fatty acid that induces apoptosis in liver cells is palmitic acid. Oleic acid is discovered to be more steatogenic but less apoptotic than palmitic acid [19,32]. Co-incubation of liver cells with both palmitic and oleic acid results in higher amount of fat accumulation than incubation with only palmitic acid. This co-incubation also lowers palmitate-mediated apoptosis, indicating a protective feature of oleic acid [19,32]. In this study, HepG2 cells were incubated with a mixture of PA and OA (1:2) respectively, to develop a model to test the effect of the PTP1B inhibitor on gluconeogenesis *in vitro*. To determine if HepG2 cells accumulate lipid, Oil red O was performed, flow cytometry based on Nile red staining was performed to determine the intracellular lipid content.

With this experiment, the quantification with ImageJ shows that HepG2 cell line can accumulate FFA, which was stained by ORO and viewed under microscope x 400 magnification. The cells were cultured in high glucose media, some lipids were seen in control but fewer in number compared to the treated cells. This result is similar with the study of Chavez-Tapia et al. (2011) [33], reaching the conclusion that hepatic cell line (HuH7) and no tumoral immortalized human hepatocytes (IHH) used could accumulate FFA, and the increase in fat content was not related to critical deterioration of the cell integrity, in accordance with clinical and *in vivo* experimental information.

Yao, *et al*., 2011 demonstrate that 1 mM concentration of FFAs caused fat accumulation but not lipotoxicity [34]; however, group of HepG2 cells treated with 2 and 3 mM FFAs significantly increased the lipotoxicity in cells. The proliferation assay was used to determine how proliferative HepG2 cells are and to confirm if the concentration of FFA causes lipotoxicity in this study. In this study, after incubation in 4 hours, there was 17% reduction of Alamar blue in both the control and treated cells, while 20-hour incubation gave 52% and 57% reduction of Alamar blue in control and treated wells, respectively. This means that the cells are dividing rapidly in 20 hours than 4 hours because of long period of incubation. 1 mM FFA concentration showed no significant difference in the proliferation of the treated HepG2 cells compared to the control cells; this indicates that 1 mM FFAs cause's lipid accumulation but not cell toxicity. This is similar to the previous study [34] on lipotoxicity in HepG2 cells that support the findings in this practical. In 4-hour incubation, treated cells are differentiating at 95% of the rate of control cells, this indicates that the treated cells have reduced Alamar blue by 95% of what the control had done or growth in treated is inhibited by 5% compared to control. However, in 20-hour incubation, treated cells are differentiating at 112% of the rate of control cells, this indicates that there is 0% growth inhibition in the treated cells compared to control cells.

To determine the intracellular lipid droplets, HepG2 cells were stained with Nile red. Exposure of cells to 1 mM FFA for 24 hours induced accumulation of lipid. Figure 2 (A and B) shows the forward and side scatter of the unstained control and unstained treated cells

respectively. The forward scatter is used to identify the size and shape of the cells. The side scatter is used to determine the complexity of the internal environment of the cell. Cells with high complexity in the internal environment will have higher side scatter signals than cells with no or low complexity [35]. In figure 2A and 2B, the forward scatter shows a single cell population, which indicates that almost HepG2 cells have the same size. Figure 2B has a higher side scatter than figure 2A, which shows cells in figure 2B have more internal complexity than cells in figure 2A as a result of treating cells with 1 mM FFAs. Microscopic image shows the presence of cytoplasmic lipid droplets. This data was confirmed by flow cytometry in figure 2. The highest peak was observed in figure 2H (stained treated cells) compared to figure 2G (stained control cells) due to fat accumulation in these cells. When the cells were treated with 1 mM FFA and stained with Nile red, the peak shifted to the right, which corresponded to the significant increase 6x in the geometric mean fluorescence intensity compared to the stained control cells. This result is similar to the result of the previous study [34] that shows an increase in fluorescence intensity of lipid in stained treated cells. Nile red attached to the lipid in the treated cells could make the internal environment in the cells become more complex. The more complex the internal environment of the cell was, the higher the side scatter signal was. This is why the fluorescent intensity of the treated cells was higher 6 times than that of the control cells. Bradford assay was used to measure the concentration of protein in a solution, which was proposed by the study of Cheng et al. (2016) [36]. As a result, the highest protein concentration was in the suspension of control cells while the lowest concentration of protein was in the pellet of control cells as well.

CONCLUSION

PTP1B is an important molecular target of the treatment of diabetes and obesity. This inhibitor is targeted to reduce the complications that are associated with obesity such as hepatic steatosis and type 2 diabetes. It was assumed that the cells may not have accumulate the FFA in their own when the inhibitor was tested on the model in all the assays performed above (Oil red O, Nile red, proliferation assay and flow cytometry). The results show that HepG2 cells were induced to lipid over accumulation by mixtures of oleate and palmitate acids. 1 mM FFA did not affect the cell integrity and did not cause lipotoxicity of the cells. FFAs should be used with different concentrations of FFAs to develop further the model. The intracellular lipid accumulation in cells treated with FFA media was detected by Nile red fluorescence assay. Obviously, the fluorescence signals of stained treated cells were higher than those of stained untreated cells, and also higher than signals of treated cells without being stained with Nile red dye. Cells treated with FFAs and stained with Annexin V/propidium iodide should be assayed for apoptosis using flow cytometry in further experiments.

Ethical approval and consent: NA

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