INTRODUCTION

The ultimate goal of endodontic treatment is the achievement of biological healing in the form of regeneration. Network regeneration is the process of healing by restoring the natural architecture and biological functions of damaged tissue, whereas repair is the restoration of tissue with replacement or scar tissue, without the return of function [1]. Regeneration restores the vitality of the tooth so that it can function like a healthy tooth. However, the conventional endodontic treatment procedures performed currently replace damaged tissue with biocompatible synthetic materials, but do not restore the biological functions to resemble that of normal tissues [2].

The development of science and network engineering technology is proving to be a breakthrough in the field of endodontics with the inclusion of stem cells, growth factors, and scaffolds, which are known as the triad of endodontic engineering. The first element of the tissue engineering triad is the stem cells. Studies on the isolation of dental stem cells have developed rapidly, especially after its isolation in pulp stem cells in 2000 [3]. Dental pulp stem cells (DPSC) have a high rate of proliferation even after many subcultures. In addition, DPSC have the ability to modify due to its high rate of differentiation. DPSC are present along with stem cells of apical papilla (SCAP) in the open apex; therefore, they continue to carry the morphogenetic information derived from SCAP. The characteristics and multiline differentiation potential of DPSC make them an important part of regenerative care [4].

Regenerative endodontic treatment has been a promising alternative treatment for the treatment of immature teeth with pulp necrosis [5,6] and can replace conventional endodontic treatment methods when used in conjunction with tissue engineering [7–9]. This will shift the paradigm of endodontic treatment from conventional/reparative to regenerative [1,10].

Numerous studies on regenerative endodontics using successful revascularization procedures in immature teeth with pulp necrosis and continued bleeding into the canal system due to over-instrumentation have been published so far [1,5]. The most important aspect of this clinical procedure is the chemical disinfection of the root canal system using irrigation materials and root canal medicaments for several weeks [5,6]. Root canal medicaments should ideally have antibacterial properties and provide a conducive environment so that stem cells can regenerate or heal [11,12]. Therefore, the concentration of the medicaments used in regenerative endodontic procedures should be effective against bacteria but not toxic to the stem cells [6].

METHODS

The study protocol had been approved by the Dental Research Ethics Committee, Faculty of Dentistry, Universitas Indonesia. Mesenchymal stem cells from the pulp of immature permanent third molars with open apices (primary culture) were used in this study. Inclusion criteria were as follows: Permanent third molar teeth indicated for extraction, from male or female patients aged <20 years, with radiographic evidence of immature teeth with open apices (>1.5 mm) during the development stage. The exclusion criteria were as follows: Permanent third molars with caries or pulp and periapical disease, cultures contaminated with fungi/bacteria, and cells that did not grow well during the first and subsequent passages.

Primary cells were isolated from newly extracted immature third molar teeth. Pulp tissue was removed, chopped into 2 mm × 2 mm × 1 mm fragments and incubated in a Petri dish with 0.25% trypsin for 5 min. The cells were added into 6-well plates containing complete Dulbecco’s modified Eagle’s medium and incubated at 37°C and 5% CO2 until confluent.

For the immunofluorescence test, cells were plated in chamber slides at a density of 5000 cells and incubated at 37°C and 5% CO2 for 3 days. On day 3, the medium was removed, and the cells were fixed using acetone-methanol absolute solution for 2 min. After fixation, the cells were washed with PBS solution and dried. Primary antibodies...
were dissolved in PBS at concentrations of 100%, 50%, and 25%, and 100 μL was added into each chamber. The cells were incubated with the antibodies at 37°C for 60 min; followed by which, they were washed again with PBS solution. Secondary antibody fluorescein isothiocyanate was added, and the cells were incubated at 37°C for 60 min. After washing with PBS, the cells were dyed with Evans Blue, rinsed with aquadest, and dried. Subsequently, the cell specimens were observed under a fluorescence microscope.

The cells were divided into two groups, control and treatment cells exposed to the test materials: triple antibiotic paste (TAP), Ledermix®, a paste containing demeclocycline and trimethoprim, and pure calcium hydroxide powder (Ca(OH)₂), at concentrations of 0.1 and 1 mg/mL.

TAP was prepared by mixing 500 mg of metronidazole (Indofarma, Indonesia), 200 mg of ciprofloxacin (Bernofarm, Indonesia), and 100 mg of doxycycline (OGB Dexas, Indonesia) at a 1:1:1 ratio (3Mix) and added to a mixture of macrogol (M) and propylene glycol (P; ratio, 1:1), which acted as the solvent (MP). The antibiotic mixture and the solvent were stirred evenly until a putty consistency was achieved. A (OH)₂ paste was prepared by mixing Ca(OH)₂ powder (Merck, Germany) with aquadest to form a sandy paste-like consistency. TAP, Ledermix® (Riemser Pharma GmbH, Germany), and Ca(OH)₂ pastes were diluted in the medium to concentrations of 0.1 and 1 mg/mL.

For the MTT test, the cells were incubated in 96-well plates for 24 h. The cell culture medium was discarded, and 100 μL of test material was added per well. The cells were incubated at 37°C and 5% CO₂ for 48 h. MTT compound (100 μL) was added, and the cells were incubated at 37°C and 5% CO₂ for 4 h. The cell supernatant was removed, and the formazan crystals formed were dissolved in 70% ethanol. Optical density (OD) readings were obtained using a microplate reader at a wavelength of 595 nm.

The data obtained were analyzed by one-way analysis of variance and post hoc Bonferroni’s tests with a 95% confidence interval to compare the OD values between the control group and the treatment group.

RESULTS

An immunofluorescence test was performed using the STRO-1 antibody to confirm the mesenchymal nature of the primary culture cells from the dental pulp. Microscopic picture of the test results is shown in Fig. 1.

The figure above shows a red cell image with no primary antibody attached to the cell antigen. Thus, secondary antibodies cannot react with the primary antibody and produce a green luminescence. On the other hand, green luminescence indicates that the cell is positive against STRO-1 and is a mesenchymal stem cell.

Microscopic images of the cells in the control and treatment groups after incubation for 2 days on a 96-well plate are shown in Figs. 2-5.

Fig. 2 shows the microscopic images of the control cell cultures that were not exposed to bioactive compounds. Numerous, evenly dispersed fibroblasts presenting as small spindle-shaped cells with a thin cytoplasmic extension were noted. Microscopic images of cells in the TAP group revealed shortened cells that were in fewer numbers when compared with the control group (Fig. 3). The morphology of cells in the Ledermix® treatment group was also altered, and the numbers were reduced (Fig. 4), whereas in the Ca(OH)₂, treatment group the morphology of the cells was similar to that in the control group with a sufficiently high number of cells (Fig. 5).

The OD was measured in the MTT assay, and the values were expressed as a percentage of the control group. The mean OD values and percentages of cell viability are shown in Table 1, whereas Table 2 illustrates the significant differences in cell viability between the treatment and control groups.

The highest value of cell viability among the cell groups exposed to the 0.1 mg/mL of the test material was noted with Ca(OH)₂ (45.5% ± 5.8%), and the lowest was noted with Ledermix® (15.1% ± 3.4%). TAP was the most effective in reducing the viability of cells exposed to 1 mg/mL concentration of the test material, whereas Ledermix® appeared to be the least effective (Table 1).

The cell viability in all treatment groups was significantly lower than that of the control group at concentrations of both 0.1 and 1 mg/mL (p<0.05).
Fig. 4: Microscopic images of the Ledermix® treatment group cells after incubation for 2 days (×32 magnification). Treatment groups exposed to Ledermix® at a concentration of 0.1 mg/mL (a) and 1 mg/mL (b)

Fig. 5: Microscopic images of calcium hydroxide (Ca(OH)₂) treatment group cells after incubation for 2 days (×32 magnification). Treatment group exposed to Ca(OH)₂ at a concentration of 0.1 mg/mL (a) and 1 mg/mL (b)

Table 1: Mean optical density values and percentages of cell viability between the control and treatment groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean value of OD±SD</th>
<th>Cell viability±SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.325±0.025</td>
<td>100±7.7</td>
</tr>
<tr>
<td>Concentration 0.1 mg/ml TAP</td>
<td>0.139±0.016</td>
<td>42.8±4.9</td>
</tr>
<tr>
<td>Ledermix®</td>
<td>0.049±0.011</td>
<td>15.1±3.4</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>0.148±0.019</td>
<td>45.5±5.8</td>
</tr>
<tr>
<td>Concentration 1 mg/ml TAP</td>
<td>0.121±0.003</td>
<td>37.2±0.9</td>
</tr>
<tr>
<td>Ledermix®</td>
<td>0.024±0.006</td>
<td>7.4±1.8</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>0.097±0.014</td>
<td>29.8±4.3</td>
</tr>
</tbody>
</table>

OD: Optical density, TAP: Triple antibiotic paste, SD: Standard deviation, Ca(OH)₂: Calcium hydroxide

Table 2: Significance differences in cell viability between the treatment and control groups at concentrations of 0.1 mg/mL and 1 mg/mL (p<0.05)

<table>
<thead>
<tr>
<th>Concentration of test material</th>
<th>Control versus TAP</th>
<th>Control versus Ledermix®</th>
<th>Control versus Ca(OH)₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mg/ml</td>
<td>0.001*</td>
<td>0.000*</td>
<td>0.001*</td>
</tr>
<tr>
<td>1 mg/ml</td>
<td>0.015*</td>
<td>0.000*</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

*p<0.05. Ca(OH)₂: Calcium hydroxide, TAP: Triple antibiotic paste

Table 3: Differences in cell viability among the three treatment groups exposed to the test material at concentrations of 0.1 and 1 mg/mL (p<0.05)

Table 4: Differences in cell viability among the TAP, Ledermix®, and Ca(OH)₂ treatment groups based on the concentration of the test materials (p<0.05)

<table>
<thead>
<tr>
<th>Group</th>
<th>TAP versus Ledermix®</th>
<th>TAP versus Ca(OH)₂</th>
<th>Ca(OH)₂ versus Ledermix®</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mg/ml</td>
<td>0.002*</td>
<td>1.000</td>
<td>0.000*</td>
</tr>
<tr>
<td>1 mg/ml</td>
<td>0.000*</td>
<td>1.000</td>
<td>0.004*</td>
</tr>
</tbody>
</table>

*p<0.05. Ca(OH)₂: Calcium hydroxide, TAP: Triple antibiotic paste

DISCUSSION

The purpose of endodontic regeneration is the achievement of biological recovery, which reproduces the natural architecture and original biological functions of the tissue. A crucial stage in this treatment is the chemical disinfection of the root canal system by irrigation and placing of medicaments in the root canal for several weeks to kill bacteria and germs that are still present deep within the dentinal tubules. Very few studies on endodontic regeneration have been conducted in Indonesia; hence, this study aimed to evaluate the effects of root canal medicaments commonly used in root canal treatment on the viability of mesenchymal stem cells.

In this study, the primary culture of mesenchyme DPSC was used on the basis of the study by Pérez et al. (2003), who reported that the results of primary cells used to test an endodontic material would be much closer to the actual condition when compared with secondary cells [13]. SCAP is commonly used in regenerative studies because it has a higher proliferative capacity when compared with DPSC [14]. Nonetheless, we used DPSC in the current study because they carry morphogenetic information derived from SCAP. DPSC is an integral part of SCAP and is separated by an apical cell-rich zone at the odontogenesis stage, especially in immature teeth with incompletely closed root apices [15]. Chuensombat et al. (2013) reported that the survival of DPSC in infected root canals indicates their ability to regenerate [16]. Moreover, the volume of DPSC is 10 times higher than that of primary cells from SCAP, whereas the levels of contamination are lower because it is more coronally located, thus minimizing the risk of contact with the external environment at the time of collection.

There is heterogeneity in the mesenchymal stem cell population, with cells expressing different molecular markers. DPSC is an adult mesenchymal stem cell that can be characterized in vitro by STRO-1 [14,17,18], a monoclonal antibody that marks the subpopulation of mesenchymal stem cells as a colony-forming unit fibroblast because the morphology of mesenchymal stem cells resembles that of fibroblasts in vitro [19,20]. The selection of STRO-1 as a DSPC molecular marker in this study is based on previous studies, which demonstrated the consistent specificity of STRO-1 as a mesenchymal stem marker [18,21]. In the present study, STRO-1 was detected on DPSC using the indirect immunofluorescence test method.
Cell viability in the treatment group was lower than that in the control group (Tables 1 and 2). Thus, the first hypothesis that TAP and Ledermix® can decrease the viability of DPSC was accepted, whereas the second hypothesis that Ca(OH)₂ can increase the viability of DPSC was rejected.

The viability of cells in the TAP group at concentrations of 0.1 and 1 mg/mL was significantly lower when compared with that in the control group. These results are consistent with those reported by Chensombat et al. (2013), where TAP had a toxic effect on pulp and apical papilla cells at a concentration of 25 µg/mL. This is due to the low pH of the TAP (4–6.5), caused by the release of hydrogen ions from the hydrochloride group in minocycline hydrochloride and ciprofloxacin hydrochloride, thus causing unfavorable acidic conditions in the cell culture. The low pH also maintains TAP solubility enabling it to enter the cell, thereby increasing its cytotoxicity. It is known that metronidazole has no toxic properties due to its neutral pH [16]. Therefore, alternative antibiotics with neutral pH and potent antibacterial properties, instead of minocycline and ciprofloxacin, should be selected.

As seen in Table 1, the cell viability values in the Ledermix® treatment group were very low (<30%) and may be included in the high toxicity category based on the Dahl et al. criteria [27]. The decrease in cell viability with a concentration of 1 mg/mL Ledermix® was significantly higher than that with a concentration of 0.1 mg/mL. This finding is supported by Taylor et al. [1989] who reported that Ledermix® can kill mouse fibroblast cells at very low concentrations of 0.001 mg/mL [28]. The cytotoxic properties of Ledermix®, especially the corticosteroid component, are exerted by inhibiting phagocytosis and DNA/proteins synthesis during the cell mitosis process. Thus, cell replication is inhibited, and the healing process is impaired [28,29]. This was evidenced by Oliveira et al. (2009) who used mouse pulp cells exposed to antibiotic-corticosteroids (Otosporin®) for 72 h to demonstrate delays in tissue healing after treatment [30]. However, Taylor et al. [1989] stated that the toxic effects can be inhibited by mixing with Pulpdent® (Ca(OH)₂) [28]. These findings indicate that the use of Ledermix® as a medicament in regenerative endodontics should be avoided as it may interfere with the cell regeneration process. Alternatively, they may be used at very low concentrations or in conjunction with Ca(OH)₂.

The viability values of cells exposed to 0.1 or 1 mg/mL Ca(OH)₂ was also decreased when compared with the control group. This may be attributed to the high pH of the Ca(OH)₂ (12.5–12.8), which can cause cell/tissue necrosis immediately after contact, thus destroying cells that have the potential to regenerate [31]. Giro et al. [2010] examined the effects of Ca(OH)₂ on pulp cells during the direct pulp capping procedure and observed a layer of coagulation necrosis under the capping agent in all treatment groups after 7 days; however, pulp cells were still present within the necrotic tissue with very few infiltrates of inflammatory cells [32]. Subsequently, after 30 days, the specimens showed normal elongation of the monolayer cells associated with hard tissue deposition near the wound area, thus implying that Ca(OH)₂ can be used over a long period of time. The formation of mineralized tissue after contact with Ca(OH)₂ can be seen on the 7th–10th day after application of the compound. In the present study, incubation after exposure of the test material was only for 2 days. The duration of this exposure was based on the number of cells planted (as many as 5000 cells) in the 96 well plates to achieve confluence within 48 h.

The test material used in this study was dissolved in the culture medium until the concentrations of 0.1 and 1 mg/mL were obtained. These concentration values were selected on the basis of a previous study by Ruparel et al. (2012), which states that TAP concentrations above 1 mg/mL have a lethal effect [6]. The concentrations of the test material were effective in reducing cell viability, especially in the Ledermix® and Ca(OH)₂ treatment groups, in the current study. However, in the TAP treatment group, the decrease in cell viability was not statistically significant. This contradicts with the results of the aforementioned study, where concentrations of 1 mg/mL TAP had a toxic effect, whereas, at a concentration of 0.1 mg/mL, no detectable toxic effect was noted; on the other hand, Ca(OH)₂ at high concentrations [100 mg/mL] increased cell proliferation [6]. These differences in results may be due to the different methods used, wherein a cell insert was used by Ruparel et al. so that the material did not come in direct contact with the cell, whereas in the present study, we used the direct contact method. The use of direct contact simulates the clinical setting where the root canal medication used in current endodontic treatment needs to be in direct contact to be more effective.

The root canal medicaments that were least effective in decreasing cell viability were TAP and Ca(OH)₂. Statistical significance notwithstanding, the cell viability value in the TAP group (concentration 0.1 mg/mL) was lower than that of Ca(OH)₂ at a concentration of 0.1 mg/mL; on the other hand, the cell viability value in the TAP group (concentration 1 mg/mL) was higher than that of Ca(OH)₂ at a concentration of 1 mg/mL. These findings indicate that TAP and Ca(OH)₂ have the same effects on the viability of DPSC cells.

The three root canal medicaments, TAP, Ledermix®, and Ca(OH)₂, were found to decrease the viability of dental pulp mesenchymal stem cells. The results of this in vitro study, which was purely a cellular study, cannot be compared directly with those of other in vivo studies. However, it is important to focus on the concentration of and duration of exposure to the medicinal ingredients before selection for use in regenerative care; the medicaments must be effective against bacteria and not cytotoxic for the stem cells. In addition, further in vivo studies in animals and humans are required to re-evaluate the cytotoxicity and biocompatibility of these medicaments.

CONCLUSIONS

From this study, it can be concluded that the root canal medicaments TAP, Ledermix®, and Ca(OH)₂ can decrease the viability of stem cells obtained from the pulp mesenchymal stem cells. TAP and Ca(OH)₂ were the least effective in reducing cell viability, whereas Ledermix® has the highest effect in decreasing the viability of the stem cells of the pulp.

CONFLICTS OF INTEREST

There are no conflicts of interest to declare.

REFERENCES


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