Comparative Evaluation of Various Mesenchymal Stem Cells in Combination with B-Tricalcium Phosphate

Mehrnoosh Hassan Shahriyari [a], Sepanta Housseinpour [b], Zahrasadat Paknejad [c], Arash Khojasteh [d*]

[a] Research Institute of Dental Sciences, Dental school, Shahid Beheshti University of Medical Sciences, Tehran-Iran; [b] Department of Tissue Engineering, School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran-Iran; [c] Medical Nanotechnology and Tissue Engineering Research Center, Shahid Beheshti University of Medical Sciences, Tehran-Iran; [d] Research Institute of Dental Sciences, Dental school, School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran-Iran.

Corresponding author: Arash Khojasteh, Shahid Beheshti University of Medical Science, Daneshjou Boulevard, Evin, Tehran, Iran, P.O. 19839. ***E-mail***: arashkhojasteh@sbmu.ac.ir; ***Tel***: +98-21 88507687

Submitted: 2017-02-21; **Accepted:** 2017-04-16; **DOI**: *10.22037/rrr.v2i2.21731*

Introduction: The present study was aimed to evaluate and compare adhesion, proliferation, and differentiation of stem cells originated from dental pulp, Buccal fat pad tissue, umbilical cord blood and bone marrow on the β- TCP scaffold. **Materials and Methods**: Human mesenchymal stem cells originated from dental pulp, Buccal fat pad tissue, umbilical cord blood and bone marrow were assessed in this study. The characteristics of mesenchymal stem cells evaluated by flow-cytometry. Biological properties such as cell number, alkaline phosphatase (ALP) activity, alizarin red and MTT assay evaluated during cell culture. The morphology of cells culture was also examined using a scanning electron microscope (SEM). The MTT assay results represented that the proliferation was time-dependent and the rate of proliferation and viability of any four mesenchymal stem cells were the same. **Results:** The SEM of hBFPSCs, hBMSCs, hDPSCs, hUCSCs at 5 days indicated that hBFPSCs have higher attachment. ALP enzyme activities revealed the highest at day 21 when the cells were cultured in differentiation media. The alizarin red staining results indicated a clear mineralization of hBMSCs is dramatically higher from three mesenchymal stem cells. Our findings showed that the origins of MSCs impel their proliferative and osteogenic sufficiency and thus influence their application as a cell sources for bone tissue engineering. **Conclusion:** Despite BMSCs are the best nominee for cell based bone regeneration according to the existing evidences, in clinical and in vivo conditions there are many circumstances may be encountered bone healing.

Keywords: Mesenchymal stem cell Dental pulp stem cell (hDPSCs) ; Bone marrow stem cell (hBMSCs) ; Buccal fat pad (hBFPSCs) ; unrestricted somatic stem cells (UCSCs) ; β- TCP

Introduction

Mesenchymal stem cells (MSCs) have been investigated as promising candidates for use in new cell-based therapy strategies. Cell-based therapies for bone regeneration commonly utilized mesenchymal stem cells (MSCs) derived from bone marrow (1-6). MSCs also can be isolated from a wide diversity of tissues such as; synovial membrane, skeletal muscle, adipose tissue, peripheral blood, periosteum, umbilical cord blood and dental tissues (7-10). There are increasing studies to investigate alternative source of mesenchymal stem cells be replaced to overcome the limitations of bone marrow-derived mesenchymal stem cells (BMSCs) (11-14).

Buccal fat pad tissue is one of the richest sources of MSCs. Being Easy to harvest, obtaining the high number of the primary cells, having fewer risks and pain for removal of the larger volume of tissue and finally having high proliferative capacity have led buccal fat pad stem cells (BFPSCs) become an appropriate substitution MSCs (12, 15, 16).

Recently, the unrestricted somatic stem cells (UCSCs) are separated from human umbilical cord blood. These cells have the potential to be distinguished into three embryonic layers and also they remain undifferentiated without deformation after long- term proliferation in vivo. In comparison with BMSCs, the isolation of these non-invasive cells is done much easier. Also UCSCs have better growth kinetics and a long lifetime i.e., up to more than 20 passages. In addition, in term of ethical issues and immune system reactions, these cells are less problematic than embryonic cells (17).

Dental pulp stem cells (DPSCs) are commonly obtained from wisdom teeth, deciduous teeth and apical papilla. Their

ability in regeneration of bones has been showed in various studies. It has been shown that DPSCs have more willing to be distinguished to transgenic/odontogenic categories (12, 17, 18).

Studies showed that the proliferation and differentiation capacities of MSCs are influenced by several factors including tissue origins, age of donor, and cultivating factors (19). There is controversies in MSC-related literature regarding optimal source of MSC with high proliferation and differentiation potentials. Hence, the present study aimed to evaluate and compare the adhesion, proliferate, and differentiation of stem cells derived from dental pulp, buccal fat pad tissue, umbilical cord blood and bone marrow cultured on the β-tricalcium phosphate (β-TCP).

Materials and Methods

Stem cell culture

hDPSCs were derived from pulp tissues obtained from wisdom teeth from healthy individuals in Department of oral and maxillofacial surgery at Shahid Beheshti University of Medical Sciences. After washing in sterile phosphate-buffered saline (PBS) (Sigma-Aldrich, Nst. Louis, Mo, United States), dental pulp were individually isolated from the pulp chamber of extracted teeth with sterile instruments (20).

hBFPSCs were isolated from buccal fat pat tissues of a healthy individual who electively subjected to an aesthetic midface improvement (21). The pulp and adipose tissues were digested in a solution of 1% collagenase type I (Sigma-Aldrich, St. Louis, Mo, United States) for 1 hour at 37°C in incubator shaker. Then cells were re-suspend in growth medium containing Dulbecco's Modified Eagle Medium (DMEM) (Life Technologies, Carlsbad, CA, United States), 20% fetal bovine serum (FBS) (Life Technologies, Carlsbad, CA, United States), 1% Penicillin-Streptomycin 10,000 u/ml (Life Technologies, Carlsbad, CA, United States). Cell suspension was transferred to a T-25 flask and incubated at 37°C and 5% CO_2. Cells were cultured after 80-90% confluency. Medium were changed every 3 days. Cells were trypsinised using 0.25% trypsin-EDTA (Life Technologies. Carlsbad, CA, United States) (22).

hBMSCs and hUCSCs were obtained from stem cell bank of Bonyakhte institute, Tehran, Iran.

Characterization of stem cells

In order to check the percentage of MSCs (hBFPSCs, hBMSCs, hUCSCs, hDPSCs) phenotype, flow cytometry analysis for the expression of CD44, CD90, CD73, CD 105, CD45, and CD 34 were performed.

Cell seeding

β -TCP granules (Lasak, Praha, Czech Republic) with pore size of 100-200 μm (macro pores) and 1-5 μm (micro pores) were used as 3D scaffold. 0.27 grams of β -TCP granules were placed in 24-well plates. Mesenchymal stem cells were cultured in medium (high glucose DMEM, 10% FBS, 1% Penicillin streptomycin) (23). Cells were harvested after 80-90 % confluence. 5×10^4 cells were suspended in 10 ml medium were seeded onto scaffolds. 1 hour, cells were incubated for cell attachment on the surface scaffolds; afterwards additional culture medium was added on scaffolds for overnight. Cell-scaffold were cultured in standard growth or osteogenic (StemPro® Osteogenesis Differentiation Kit, Thermo Fisher scientific, Waltham, Massachusetts, United States) medium. Experiments were performed in triplicate.

Cell adhesion and morphology evaluation

The surface morphology of β-TCP scaffolds was examined using SEM, the cells on the scaffolds were fixed by 2.5% glutaraldehyde for 2 hours at room temperature. Dehydration cell-scaffold was done in a series of increasing concentrations of ethanol in distilled water 30%, 70%, 80%, 90%, and 100% for 10 min per each concentration. The samples were air- dried for 24 h. Finally, the scaffolds were sputter-coated with gold before SEM imaging (Hitachi, Tokyo, Japan).

Cell viability evaluation

To assess the proliferation of stem cells, 3-(4,5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) (Sigma, St. Louis, Missouri, United States) and DNA counting assay were performed. After 24 and 72 h, 20 μL of MTT was added and incubated for another 4 h at 37°C. The supernatant was removed and dimethyl sulfoxide (DMSO) (Roche, Basel, Switzerland) was added to each well for 10 min to dissolve any formazan crystals formation. The absorbance was read by absorption at 570 nm using ELIZA reader (BioTek, Winooski, VT, USA) in 96 well-plate. Cell-scaffolds were 3D cultured in stem cell growth medium with 7 and 14 days.

Proliferation of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) were evaluated using DNA counting assay.

Briefly, cell-scaffolds were lyzed in Trizol solution (Life Technologies, Carlsbad, CA, United States) and incubated at room temperature for 10 min. This was followed by phase separation step by adding chloroform, then cold centrifugation to collect the DNA as a pellet in the bottom of the micro-centrifuge tubes. DNA then was washed and dissolved in 8 millimolar concentration NaoH solution. The DNA concentration was measured at the wavelength of 260 nm by Nanodrop (Thermo Scientific, Waltham, MA, United States).

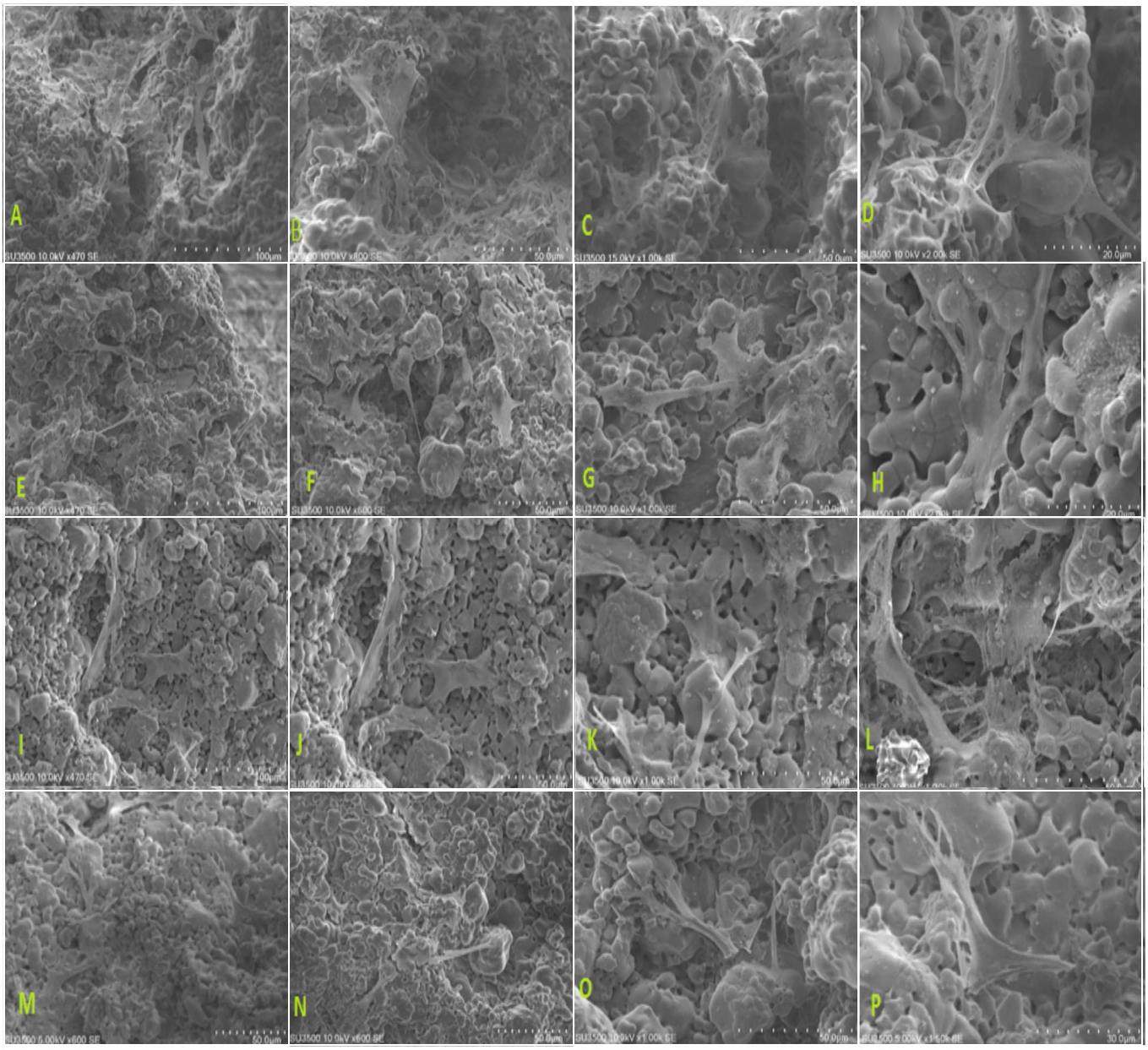

Figure 1. Evaluation of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) attachment on β-TCP granules by Scanning electron microscopy (SEM). Four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) were grown in standard stem cell medium. A-D (hBFPSCs); E-H (hBMSCs); I-H (hDPSCs); M-P (hUCSCs) on β-TCP granules. Note SEM figures showed that adhesion and proliferation of hBFPSCs on β-TCP granules is obviously higher between other three mesenchymal stem cells (hBMSCs, hDPSCs, hUCSCs)

Osteogenic differentiation assay

Cells were seeded at a density of 5×10^4 on β-TCP scaffolds in growth medium overnight. Then, the culture medium was changed to osteogenic medium. Osteogenic medium was changed every 3 days. Cells were harvested at 7 and 21 days. Osteogenic differentiation was evaluated by alkaline phosphatase (ALP) activity assay. The cells were lysed by RIPA buffer (Thermo scientific, Waltham, Massachusetts, United States) on ice for adjustment 30 minutes. The resulting mixture of lysis buffer, and then was centrifuged at 15000 rpm for 30 min at 4 ˚C. The cell lysate mixed with *p*-nitrophenol phosphate substrate solution (Sigma Aldrich, St. Louis, Missouri, United States). After incubation at 37 °C for 30 min, the above mixture was added to 0.5(N) NaOH to stop the reaction. The absorbance at 405 nm was measured using ELIZA reader (BioTek, Winooski, VT, United States).

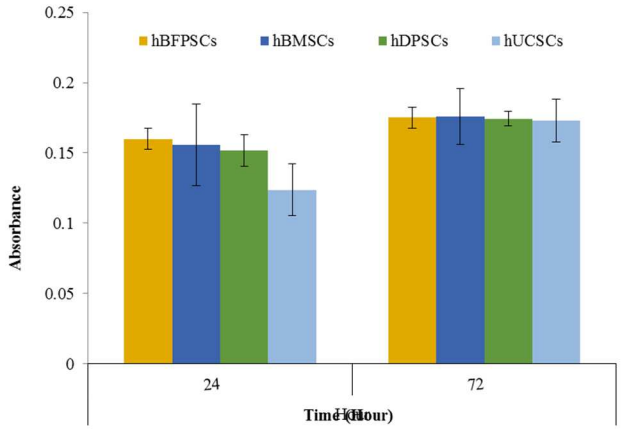

Figure 2. Evaluation of proliferation of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) in standard stem cell medium on β-TCP granules by MTT assay after 24 and 72 hours. Note that the results of MTT assay clearly revealed the percentages of cell viability at 72 hours in comparison to 24 hours are significantly increased

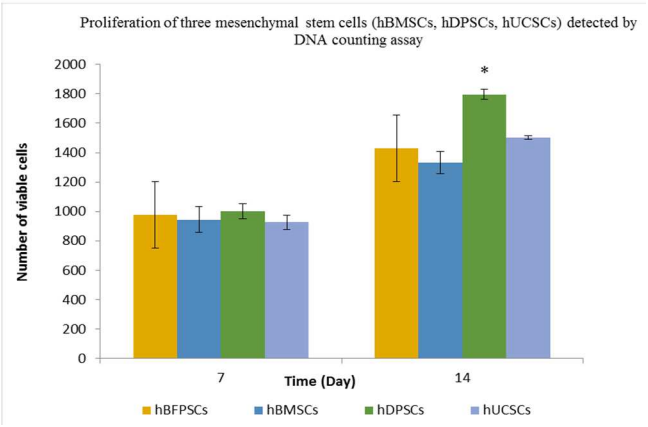

Figure 3. Evaluation of cell viability of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) in growth medium on β-TCP granules by cell counting assay after 7 and 14 days. Note that charts represent the number of cell viability are clearly increased after 14 days. Means and standard deviations of each group calculated and statistical significance was assessed by ANOVA and Tukey's post hoc test (*P<0.05 in comparison to all other groups at the same time point)

Mineralization assessment

The formation of mineralized matrix nodules was determined by alizarin red staining (Sigma, St. Louis, Missouri, United States). Trypsinizing from granules, the cells were fixed in 70% ethanol for 1h at room temperature. The fixed cells were washed with PBS

Statistical analysis

In this study, all the experiments were accomplished in triplicate and all data were analyzed by SPSS version 20.0.1 (IBM Corp., Armonk, NY, USA). Findings were compared between groups for conditioned three mesenchymal stem cells, time points and absorbance studies singly with analysis of variance ANOVA by pair-wise comparison. For all comparisons, the degree of importance was $P \leq 0.05$ and Tukey's test were used as the post hoc.

Results

Characterization of hBFPSCs, hBMSCs, hDPSCs,hUCSCs

Flow cytometric analysis of hBFPSCs, hBMSCs, hDPSCs, hUCSCs mesenchymal stem cell indicated a consistent immunophenotype in which was positive for mesenchymal markers (CD73 [SH3] and CD105 [SH2]) and cell adhesion molecules (CD 44 and CD 90). Hematopoietic markers (CD34 and CD45) were expressed at very low percentages of the cells (Table 1).

Cell adhesion and morphology

All stem cells demonstrated a similar spindle shaped morphology in 2D monolayer culture. Figure 1 represents SEM of hBFPSCs, hBMSCs, hDPSCs, hUCSCs in 3D scaffold culture at 5 days. hBFPSCs showed better adhesion to the scaffold among the study groups.

Cell proliferation and viability

Figure 2 shows the proliferation and viability of hBFPSCs, hBMSCs, hDPSCs, hUCSCs on β-TCP granules in 2D monolayer cultures quantified cell number using MTT assay at different time points 24 and 72 hours. Although hBFPSCs demonstrated the highest proliferation and hUCSCs showed the lowest proliferation within the experimental groups at 24 hours, the differences were not statistically significant. All stem cells indicated nearly the same proliferation rate after 72 hours.

Moreover, the proliferation and viability of four mesenchymal stem cells (BFPSCs, BMSCs, hDPSCs, hUCSCs) on β-TCP granules in 3D scaffold culture were quantified using DNA counting assay at 7 and 14 days (Figure 3). The results demonstrated no significant differences between experimental groups after 7 days. The amount of DNA in hDPSCs was higher significantly at 14 days (P value<0.05).

Osteogenic differentiation

ALP activity increased after 7 days and the levels were nearly the same in all groups (P>0.05). There was a statistically significant difference between ALP activities in hBFPSCs, hDPSCs, hUCSCs during differentiation into osteoblast cells, as compared to the hBMSCs on the 21st day (P value<0.05) (Figure 4).

Mineralization

High positive in alizarin red staining results were indicated throughout the all experimental groups 3D cultured on β-TCP granules at 7 and 21 days (Figure 5). Quantitative analysis of the alizarin red was clearly illustrated mineralization of hBMSCs is statistically higher than three other stem cells (P<0.05).

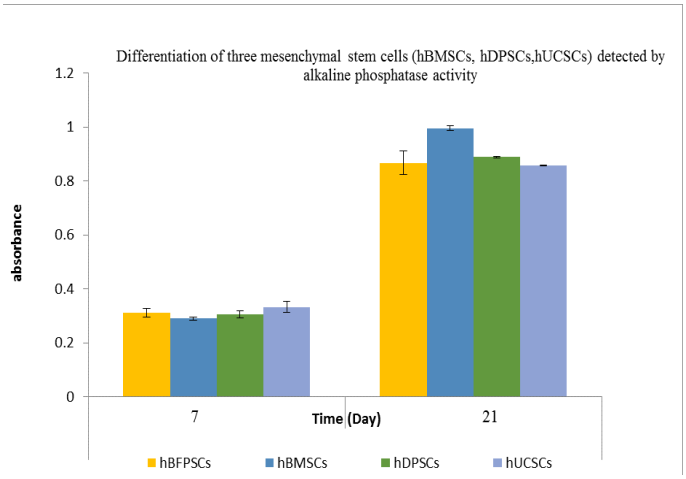

Figure 4. Evaluation of ALP of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) in osteogenic medium on β-TCP granules by ALP activity after 7 and 21 days. Note that representative graph of ALP activity of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) illustrate a clear increase in ALP activity compared to 7 days. Human bone marrow stem cells (hBMSCs) significantly showed the increase in ALP activity of three other mesenchymal stem cells (hBFPSCs, hDPSCs, hUCSCs). Means and standard deviations of each group calculated and statistical significance was assessed by ANOVA and Tukey's post hoc test (**P*<0.05 in comparison to all other groups at the same time point)

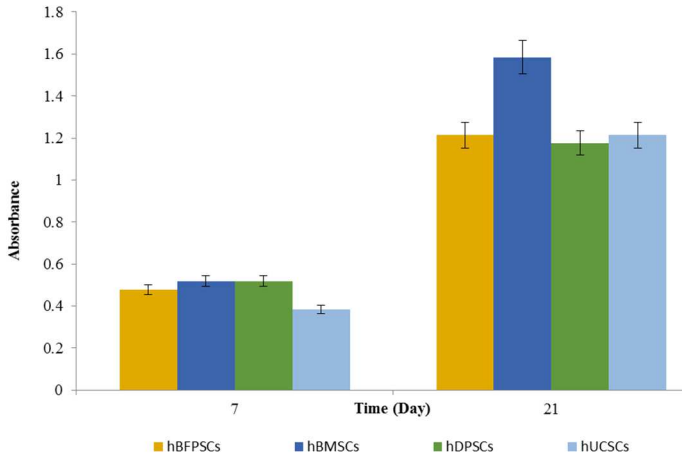

Figure 5. Evaluation of osteoblast differentiation of four mesenchymal stem cells (hBFPSCs, hBMSCs, hDPSCs, hUCSCs) in osteogenic medium on β-TCP granules by alizarin red staining after 7 and 21 days. Note that Alizarin Red staining quantification assay was clearly indicate the increase of number of mineralized nodules on day 21 in comparison 7 days. In addition, hBMSCs obviously illustrate higher mineralization between three other mesenchymal stem cells (hBFPSCs, hDPSCs, hUCSCs) after 21 days. Means and standard deviations of each group calculated and statistical significance was assessed by ANOVA and Tukey's post hoc test (**P*<0.05 in comparison to all other groups at the same time point) once. Alizarin red staining at pH 4.2 was added to each well for 30 min at room temperature. Acetic acid was included and scraped all of mixtures. Transfer mixtures to micro tubes. Incubate micro tubes at 85Ċ for 10 minutes. Quantitative analysis of alizarin red S staining was measured the absorbance at 405 nm using ELIZA reader (BioTek, Winooski, VT, United States).

Discussion

Plenty of studies conducted to compare the proliferation and differentiation of stem cells from different sources, but the question pertaining to which source can provide the ideal stem cells is still controversial. Despite of all cell therapies advantages, critical-sized defects demand scaffold placement inevitably in addition to stem cells to further support tissue regeneration. Therefore assessment of cell behaviors in contact with scaffolds is of greater importance. Rodrigues *et al.,* demonstrated that amniotic fluid- derived stem cells (AFSCs) showed higher calcium content in 2D culturing, while BMSCs outperformed AFSCs when seeded on scaffolds at the same time points. Compromising the AFSCs viability prior to mineral deposition in 2D culture can be the source of these diverse responses (25). Moreover scaffold compositions such as hydroxyapatite can act as nucleation sites and accelerate the new mineral structure formation (26). The fact can alter cell reactions with lower differentiation potential. Consequently, presence of scaffolds can elicit distinct cell responses such as proliferation and differentiation. In the present study, we compared in vitro osteogenic capacity of stem cells derived from dental pulp, buccal fat pad, umbilical cord blood and bone marrow seeded on the β-TCP, regarded as an excellent osteoconductive scaffold materials for bone tissue engineering. All stem cells showed original features of MSCs assessed by flow cytometric analysis.

Proliferation: Over the last decade, BMSCs, ASCs, UCSCs and DPSCs have become easily attainable origins of stem cell derivation for bone regeneration application. However, BMSCs are still the most repeatedly studied cells. Studies by De Ugarte *et al.,* and Shafiee *et al.,* investigated proliferation capability of human BMSCs in comparison with human adipose-derived stem cells (ASCs). They concluded that ASCs exhibited higher cell numbers, albeit with no significant differences (27, 28). Our results also indicate similar proliferation rate of these two cells observed by MTT assay. The higher proliferation capability of ASCs have been approved to be related to higher expression of cell division cycle associated 8 (CDCA8), and cyclin B2 (CCNB2) gens in ASCs than in BMSCs (29). In contrast, BrdU assay of rat stem cells showed greater viability of adipose-reside cells than BMSCs (30). Furthermore, Elkhenany recently revealed the diversity of low passaged stem cells features versus high passaged ones. They evaluated the proliferation potential of

goat adipose and bone marrow cells, and showed higher viability of low passaged BMSCs than the ASCs counterparts. However, the cells in passage 12-14 were approximately similar (29). Donor species-associated variability may be the origin of these inconsistent results as Izadpanah showed. He declared that rhesus bone marrow stem cells and human adipose tissue exhibited similar growth kinetics and shorter doubling time than rhesus ASCs and human BMSCs (31). Regarding proliferation of dental-derived stem cells from permanent or deciduous teeth and their collation to BMSCs, almost all papers reported the superior colony-forming ability and cell numbers of DPSCs than BMSCs (32-36). We found the same results by DNA counting. These outcomes support the hypothesis which indicated that dental pulp-derived stem cells possess more primitive MSC-like cells (35). Nevertheless, Study of Davis represented the lower growth curve of DPSCs compared to BMSCs and ASCs (37). Although, majority of DPSCs were isolated from intact teeth, Rajendran successfully attained stem cells from extracted primary teeth with high caries since the inflammation increased the homing of stem cells and growth factors and promote cell proliferation and differentiation (33). Stem cells with fetal origin such as ones from umbilical cord, Wharton jelly, fetal membrane and placenta undisputedly illustrated more cell numbers than ASCs or BMSCs due to their primitive source, similar to our results (38-41). In addition, they stopped proliferation in upper passage numbers with slower senescence rate. Wharton jelly's stem cells seeded on hyaluronan demonstrated higher viability compared to BMSCs and ASCs as well (42). All these differences appear to be dependent on the source of cell derivation. However, analogous tissues with different sites also can cause biological differences as ASCs from subcutaneous adipose tissue proliferated faster than Bichat's fat pad and owned considerably shorter population doubling time (43). Comparisons of other stem cell sources are depicted in table 2 and table 3 revealed combination of various MSCs and scaffolds for bone regeneration.

Differentiation: Beside to proliferation capacity, great differentiation potential of derived-stem cells plays a pivotal role in osteogenesis. We exploited ALP activity test and Alizarin red staining for the aim. Consonant results of mentioned analyses showed the superior differentiation of BMSCs compared to ASCs, DPSCs and UCSCs. Similarly, study of Shafiee, Kato and Wong reported higher amount of mineralization by BMSCs than ASCs in osteogenic medium, as a differentiation indicator (43, 44). Ongaro and his coworkers represented identical outcomes in presence of BMP-2 and exposure of pulsed electromagnetic field (45). One probable explanation of the fact could be stated by lower expression of BMP-2 and BMP-4 in ASCs (46). Although many studies corroborated the better differentiation capability of BMSCs, some approved the similar osteogenic activity of BMSCs and ASCs (47). Expansion of cells by serial passaging can alter the biological properties. Low passaged-BMSCs, which exhibited greater osteogenesis potential comparing to ASCs, lost their superior differentiation capacity when passaged to 12-14 and showed less alizarin red intensity than high passaged-ASCs (30). Our experiments were conducted by cells with 3-5 passage numbers for all sources to ensure the biological susceptibility of cells during culturing time. Regarding comparison of BMSCs and DPSCs, some researchers strongly suggested that dental derived-cells are more appropriate for bone engineering due to their higher osteoblastic differentiation (35-37), while others confirmed that both possessed similar osteogenic capacity (32-34). Intriguingly, we found that the cells expressed diverse manners when seeded on TCP granules, and BMSCs outperformed DPSCs in terms of ALP activity and calcium staining. Ponnaiyan observed that DPSCs expressed lower level of CD105, a cell migration-related marker (36). This factor may be the answer of why DPSCs did not differentiate as well as BMSCs on our scaffolds. Following 3 weeks of in vitro culturing, we demonstrated that UCSCs has less osteogenic potential than BMSCs, while they showed similar behavior to ASCs, in this regard. Hsieh and Choudhery studied the osteogenic differentiation of umbilical cord-derived stem cells and remarked the lower capacity of these fetal originated stem cells compared to BMSCs and ASCs, respectively (38, 39). Schneider *et al.,* seeded BMSCs and Wharton jelly derived-MSCs on collagen scaffolds. They observed that BMSCs expressed higher ALP and OPN markers on cultures with or without scaffolds (48). In contrast, culturing the UCSCs and BMSCs on calcium phosphate cement mixed with chitosan and polyglactin fiber represented larger percentage of mineral area on UCSCs-seeded scaffolds (49). Also, addition of osteoactivin to osteogenic medium enhanced the differentiation potential of MSCs isolated from fetal membrane and showed greater amount of stained deposition than BMSCs (41). Medium supplementation have been carried out by variety of substances such as inorganic phosphate, Dentine matrix components, BMP-2, TNF-α, IL-1b and retinoic acid (37, 50, 51). Various incubation conditions could elicit specific features of each stem cell. For instance, Rui found that addition of BMP-2 to medium increased ALP activity and Alizarin red staining in tendon derived stem cells which did not observed for BMSCs (52). Our experiments were executed under standard osteogenic medium composed of dexamethasone, ascorbic acid and β-glycerol phosphate. Together with all confounding factors, the duration of culturing prior to differentiation assessment is of key

Table 1. Expression profiles of surface markers of MSCs by flow cytometry

Cell type	CD73	CD105	CD44	CD90	CD34	CD45
hBFPSCs	+	+	+	+	-	-
hBMSCs	+	+	+	+	-	-
hDPSCs	+	+	+	+	-	-
hUCSCs	+	+	+	+	-	-

Table 2. Comparison of MSCs from various sources

Author(s)	Cell types	Culture condition	Flow cytometry	Results
Brocher J et al. ,(2013)	-BMSCs from iliac crest marrow aspirates -Human ASCs from surgical procedure or liposuction	Proliferation assessment: growth medium containing basic fibroblast growth factor + 2-mercaptoethanol +non-essential amino acids Differentiation assessment: OM P: 2	**Flow cytometry:** CD146: -ASC< BMSC CD90,CD105,CD73: -ASC, BMSC:+ CD45,CD34: -ASC, BMSC:-	**Differentiation:** ALP activity(1, 7, 14, 21 d) (ng ALP/ng protein/ml/min): ASC: 4.30 ± 1.22 BMSC: 4.37 ± 2.20 RT-PCR: -ANGPT1: BMSC>ASC-VEGF: BMSC>ASC -IL-6: BMSC>ASC-BMP-4: BMSC>ASC -BMP-2: BMSC>ASC-ADIPOQ: BMSC<ASC -NAMPT: BMSC<ASC
Elkhenany H et al.,(2016)	-Goat/caprine BMSCs -ASCs from the inguinal area of a goat	Differentiation assessment: OM Ps: -2-3: low P -12-14:high P	-	**Proliferation/viability:** CFU assay (7 d) -4 cells grew in clusters. MTS assay (2, 7, 10 d) -BMSCs ^{low} and ASCs ^{low} numbers increased linearly and notably with time but this increase pattern did not occur in the cells ^{high} - BMSCs ^{low}> ASCs ^{low} in all time points. - BMSCs ^{high} ≅ ASCs ^{high} **Differentiation:** Alizarin red staining(7, 14, 21 d) -BMSCs ^{low} > ASCs ^{high}> BMSCs ^{high}> ASCs ^{low} except for day 7 that groups showed similar mineralization. Western blot analysis(7, 14, 21 d) - p44/42 was significantly up-regulated in ASCs $^{low\ and\ high}$ - p38 and OPN were significantly up-regulated in BMSCs ^{low} on d21 after osteogenic differentiation - BMP-7 was significantly up-regulated in ASCs $^{low\ and\ high}$, but BMSCs $^{low\ and\ high}$ expressed BMP-7 lower than ASCs. Immunofluorescence (DAPI staining): - ASCs^{high} showed adipocyte morphology when induced to osteogenic differentiation
Ongaro A et al.,(2014)	-Human BMSCs -ASCs from liposuction of abdominal subcutaneous fat	Proliferation assessment: Medium composed of 60% low-glucose DMEM, linoleic acid–bovine serum albumin, Dex, ascorbic acid-2 phosphate, insulin-transferrin-sodium Selenite, 2%FBS, human Platelet-derived growth factor-BB, human epidermal growth factor. Differentiation assessment: Control medium, OM ± BMP-2 and	**Flow cytometry:** CD29, CD44, CD73, CD90, CD105: ASCs:+ CD14, CD34, CD45: ASCs:-	**Differentiation assay:** ALP activity(3, 7, 11, 14, 21, 28 d) -BMSCs: d 3: PEMFs+ BMP-2≅ PEMFs+OM≅ BMP-2+OM≅OM d 7,11: PEMFs+ BMP-2> PEMFs+OM> BMP-2+OM>OM d 14: PEMFs+ BMP-2> PEMFs+OM ≅BMP-2+OM>OM d 21,28: PEMFs+ BMP-2> BMP-2+OM> OM> PEMFs+OM -ASCs: d 3: PEMFs+ BMP-2> BMP-2+OM≅ OM> PEMFs+OM d 7: PEMFs+ BMP-2≅ BMP-2+OM> PEMFs+OM > OM d 11: PEMFs+ BMP-2> PEMFs+OM> BMP-2+OM>OM d 14: PEMFs+ BMP-2> PEMFs+OM > OM >BMP-2+OM d 21: BMP-2+OM> PEMFs+ BMP-2 ≅ OM > PEMFs+OM d 28: PEMFs+OM > PEMFs+ BMP-2> OM ≅ BMP-2+OM -In all time points: ASCs<BMSCs Alizarin red staining(14 d) -BMSCs: PEMFs+ BMP-2> PEMFs+OM> BMP-2+OM>OM -ASCs: PEMFs+ BMP-2≅PEMFs+OM> BMP-2+OM>OM ELISA of OCN level(ng /μg DNA) (3, 7, 11, 14, 21, 28 d): -BMSCs: d 3,7,11,14:PEMFs+ BMP-2≅PEMFs+OM≅BMP-2+OM ≅OM d 21, 28: PEMFs+ BMP-2> PEMFs+OM> BMP-2+OM >OM

		in the presence or absence of PEMFs exposure P: 3		-ASCs: d 3,7,11,14:PEMFs+BMP-2≅PEMFs+OM≅ BMP-2+OM ≅OM d 21, 28: PEMFs+ BMP-2≅ PEMFs+OM> BMP-2+OM ≅OM -In all time points: ASCs<BMSCs
Shafiee A et al., (2011)	-BMSCs -ASCs obtained from cosmetic liposuction	Differentiation assessment: OM P: 2	**Flow cytometry:** CD45: -BMSC, ASC:- CD90, CD73, CD105 -BMSC, ASC:+ CD133: -ASC:+ -BMSC:- CD106: -ASC:- -BMSC:?	**Proliferation/viability:** Cell count and Growth curve: - ASC> BMSC **Morphology/attachment:** -Both cells showed fibroblast-like and spindle-shaped morphology **Differentiation:** Alizarin red staining(3 w): -Both cells formed mineralized matrix. ALP activity(0, 7, 14, 21 d): -BMSC> ASC Calcium content(0, 7, 14, 21 d): -BMSC> ASC RT-PCR(0, 7, 14 d): ALP: ON d 0: BMSC≅ ASC d 0: ASC> BMSC d 7,14: BMSC> ASC d 7,14: BMSC> ASC Col I OCN d 0: ASC> BMSC d 0,7: BMSC> ASC d 7,14: BMSC≅ ASC d 14: ASC> BMSC Runx2 BMP-2 d 0,7: BMSC> ASC d 0: ASC> BMSC d 14: BMSC≅ ASC d 7: BMSC≅ ASC d 14: BMSC> ASC
De Ugarte DA et al., (2003)	-BMSCs of patients undergoing hip surgery -ASCs from patients undergoing hip surgery	Differentiation assessment: OM P: 4	-	**Proliferation/viability:** Population doubling time(h)(3-9 d): -BMSCs: 86 ± 23 -ASCs: 78 ± 26 Cell count: -The mean number of cells isolated per gram of bone marrow was considerably greater than of adipose tissue Senescence-associated β-Gal staining (%)(2 w) -BMSCs ≅ 4 -ASCs ≅ 3 **Differentiation(3 w):** ALP activity(nmol p-nitrophenol produced/min/Ìg protein): -BMSCs: 0.08 ± 0.07 -ASCs: 0.10 ± 0.12 Calcium content(Ca/µg protein): -BMSCs: 42 ± 55 -ASCs: 33 ± 38
Stöckl S et al.,(2013)	-BMSCs of rats -ASCs obtained from subcutaneous adipose tissue of rats	Differentiation assessment: OM	**Flow cytometry(%)** CD90: -BMSC, ASC (P 1,2) > 96 CD45: -BMSC (P 1)≅4 (P 2):0.52 -ASC (P 1):1.48 (P 2):2.24 CD11b: -BMSC (P 1):11.2 (P 2):1.29 -ASC (P 1):2.06 (P 2):3.27	**Differentiation(3 w)** RT-PCR P 1: -VEGFα: ASC> BMSC -ALP, Mmp13, Integrinα11, OCN: ASC< BMSC -Col1a1, SOX9, Runx2: ASC ≅ BMSC P 2: -SOX9, Integrinα11, OCN, Runx2, VEGFα, Col1a1: ASC> BMSC -MMP13: ASC< BMSC -ALP: ASC≅ BMSC Western blot analysis: -SOX9 increased strongly in ASC from P 1 to 2 while SOX9 expression reduced in BMSCs. Alizarin Red staining: -Mineralization observed in both BMSCs and ASC.
Wong H et al., (2015)	-FDSCs from the fascia of the left gluteus maximus of the rats -ASCs from the inguinal fat pad of the rats -BMSCs from the femora of the rats	Proliferation assessment: 0.5% and 10% FBS Differentiation assessment: OM P: 2	**Flow cytometry:** CD11b, CD31, CD34, CD45: -BMSCs, ASCs, FDSCs:- CD44, CD71, CD90: -BMSCs, ASCs, FDSCs:+ CD106: -BMSCs, ASCs:+ -FDSCs:-	**Proliferation/viability:** BrdU assay(2d): -0.5%FBS: FDSCs > ASCs> BMSCs -10%FBS: ASCs ≅ FDSCs> BMSCs CFU assay(14 d): -FDSCs formed more colonies with bigger size than BMSCs, ASCs. MTT assay: -0.5%FBS: FDSCs> ASCs> BMSCs -10%FBS: ASCs> FDSCs> BMSCs

				Morphology/attachment: Inverted light microscope(7,14 d) -Both cells represented similar fibroblast-like cell morphology in similar growth conditions. **Differentiation:** RT-PCR, cell marker analysis(7, 14 d) Oct4 : ASCs> FDSCs> BMSCs Sox2: ASCs> FDSCs> BMSCs Klf4: BMSCs> FDSCs> ASCs RT-PCR, gene expression analysis(7 d) -Runx2, ALP, OPN, ON in both ASCs and FDSCs were lower than in the BMSCs. Alizarin red staining(28 d) -BMSCs showed the highest amount of mineralization.
Jin Jin H et al.,(2013)	-Human BMSCs were isolated by aspiration -ASCs obtained from elective liposuction procedures -UCSCs from umbilical veins after neonatal delivery	Differentiation assessment: OM **P:** 5-12	**Flow cytometry:** CD 11b, CD 14, CD 19a, CD 34, CD 45, CD 79a, HLA DR: -BMSC, ASC, UCSC:- CD 29, CD 44, CD 7, CD 90, CD 105, CD 166, HLA ABC: -BMSC, ASC, UCSC:+	**Proliferation/viability:** CFU assay (P 3) -UCSC > BMSC or ASC Population doubling time(P 5-6) and (P 11-12) -In both Ps UCSC< BMSC, ASC Senescence-associated β-Gal staining (Gal Staining) -Expression of senescence-associated proteins in each MSC (P5> P8 >P11) - UCSC < BMSC, ASC **Differentiation:** Western blot analysis(P 12) -P53, P16, P21 proteins : -P5,8,11: UCSC< ATSC, BMSC -P12: BMSC> ASC> UCSC -P11>P8>P5
Davis OG et al. (2014)	-ASCs from inguinal fat pads of rats -BMSCs from femora of rats -DPSCs from incisors of rats	Differentiation assessment: OM DMCs were added to OM and culture medium to increase dentinogenic differentiation.	**Flow cytometry(P 2)** CD90, CD29, CD29/ CD90-positive: -BMSCs ≅ DPSCs **RT-PCR(P 0-4):** CD29, CD44, CD73, CD90, CD105(P 1-4) -ASCs, BMSCs, DPSCs: + CD34(P 0) -ASCs + -BMSCs, DPSCs –	**Proliferation/viability:** Cell count and growth curve (0, 3, 6, 9,12, 15, 18, 21 d) BMSCs ≅ ASCs> DPSCs **Differentiation:** Alizarin red staining(21 d): -DPSCs> BMSCs> ASCs -Addition of DMCs to OM showed significant increase in calcium deposition while it did not affect calcium content when added to culture medium SEM(Examination of mineralization)(21 d) -ASCs: smaller nodules -BMSCs: larger nodules -DPSCs: layer of mineralized matrix without distinct nodular formation Burning/ashing exams(Quantification of total inorganic content)(21 d) -DPSCs>BMSCs≅ASCs
Kato T et al.,(2011)	-BMSCs from femoral bone marrow of Fischer rats -ASCs from rat inguinal adipose tissue -PDLSCs from rat maxillary and mandibular molars	Differentiation assessment: -Non-differentiation condition: growth medium supplemented with *β*-glycerophosphate and ascorbic acid-2-phosphate -Differentiation condition: growth medium supplemented with *β*-glycerophosphate, ascorbic acid-2-phosphate and Dex	**Flow cytometry(1 w):** CD29, CD90: -BMSCs, ASCs, PDLSCs:+ CD31, CD44, CD45 and CD172: -BMSCs, ASCs, PDLSCs:-	**Proliferation/viability:** BrdU assay(1 w): -ASCs > BMSCs >PDLSCs **Differentiation(2 w):** ALP activity: -Non-diffrentiation condition: PDLSCs> BMSCs> ASCs ≅0 -Differentiation condition: BMSCs>PDLSCs> ASCs ≅0 Alizarin red staining: -Non-diffrentiation condition: PDLSCs:+ BMSCs, ASCs:- -Differentiation condition: BMSCs, PDLSCs:+ and BMSCs>PDLSCs ASCs:- RT–PCR analysis, Calcein uptake assay(fluorescence intensity) -Non-diffrentiation condition: PDLSCs> BMSCs >ASCs -Differentiation condition: BMSCs>PDLSCs> ASCs ≅0 OCN content(ng/ml): -Non-diffrentiation condition: PDLSCs> BMSCs ≅ ASCs ≅0 -Differentiation condition: BMSCs>PDLSCs> ASCs ≅0 RT-PCR (OCN expression) -Non-diffrentiation condition: PDLSCs> BMSCs, ASCs ≅0 -Differentiation condition: BMSCs>PDLSCs> ASCs
Rajendran, R et al.,(2013)	-DPSCs from the pulp tissue of extracted primary teeth	Differentiation assessment:	**Flow cytometery(%):** CD44: CD90:	**Proliferation/viability:** CFU Assay with various seeding cell densities of 50, 100, 500,

	with high caries -BMSCs from the iliac crest	OM	-DPSC: 99.70 - DPSC: 94.84 -BMSC: 95.42 - BMSC: 85.00 CD 105: CD 73: DPSC: 99.12 - DPSC: 99.52 BMSC: 96.34 - BMSC: 98.24 CD166: CD34: DPSC: 99.52 - DPSC: 0.08 BMSC: 98.04 - BMSC: 0.34 CD45: HLA-DR: DPSC: 0.06 - DPSC: 0.10 BMSC: 0.32 - BMSC:1.92	1000 (P 1)(14 d)(number of colonies) -DPSCs -BMSCs 50 cells seeded:1 50 cells seeded:4 100 cells seeded:8 100 cells seeded:7 500 cells seeded:33 500 cells seeded:28 1000 cells seeded:65 1000 cells seeded:44 Population doubling time(P 2) (0,1,2,3,4, 5 d) (h) -DPSCs: 30.08 -BMSCs: 32.07 **Differentiation** Von Kossa Staining(4 w): -BMSCs and DPSCs showed similar rate of osteogenic differentiation.
Alge D. et al.(2010)	-DPSCs isolated from the rat incisors -BMSCs from the tibia and femora of the same rat	Differentiation assessment: OM	**P number:** 3-5 **Flow cytometry(%)**: CD29, CD59, CD90, CD106: -DPSCs, BMSCs ≥ 95 CD45, CD11b: -DPSCs, BMSCs ≤ 5	**Proliferation/viability:** Population doubling time(P 3): -DPSC: 39.6 ± 2.5 h -BMSC: 61.7 ± 4.1 h CFU assay (colonies per 1,000 cells plated) (14-21 d): -DPSC: 151.5 ± 52.3 -BMSC: 63.8 ± 18.1 **Morphology/attachment:** SEM(2, 5 d) -Both DPSC and BMSC exhibited a fibroblastic morphology. **Differentiation:** ALP activity: (nmole/ mg*min)(3 w) -DPSC: 121.3 ± 31.3 -BMSC: 67.7 ± 5.4 Alizarin red staining(3 w): -Both cells showed mineralized nodules formation. RT-PCR(1 w): OPN: BMSC> DPSC Runx2: BMSC<DPSC
Ponnaiyan D et al., (2014)	-Human BMSCs from the sternums of patients -DPSCs from extracted third molars	Differentiation assessment: OM P:3-5	**Flow cytometry(%):** CD90: -BMSCs, DPSCs>90 CD29: -BMSCs: 32.45 ± 1.7 -DPSCs: 89.1 ± 1.4 CD105: -BMSCs: 83.14 ± 1.94 -DPSCs: 34.54 ± 1.91 CD34, CD45: -BMSCs, DPSCs<5	**Proliferation/viability:** Cell count and Growth curve(P 3)(0, 3, 6, 9, 12 d): -DPSCs> BMSCs CFU assay(%)(14 d): -BMSCs: 19.00 ± 2.16 -DPSCs: 26.67 ± 1.70 **Morphology/attachment**(early P)**:** phase contrast microscope and Wright-Giemsa staining: -Colonies and adhered fibroblast-like cells (spindle-shape and elongated morphology) of BMSCs and DPSCs observed. **Differentiation(4 w):** Alizarin red staining: -DPSCs exhibited more osteogenic potential. RT-PCR: ON: DPSCs> BMSCs ALP: DPSCs> BMSCs
Pierdomenico L et al., (2005)	-Human BMSCs -Human DPSCs from vital extracted molars	Differentiation assessment: OM	**P:**6-7 **Flow cytometry(%):** SH2, SH3, SH4: -DPSCs: 94±4 -BMSCs: 96±3 CD29,CD166: -DPSCs, BMSCs:+ CD45, CD34, CD14: -DPSCs, BMSCs:-	**Proliferation/viability:** DNA content counting by H-Thymidine labeling(15 d): -DPSCs > BMSCs Effect on T-cell proliferation(3 d): - DPSCs and BMSCs prevented T-cells proliferation 75±3% and 91±4% inhibition, respectively. **Morphology/attachment:** Light microscope(3 w): -Both cells represented spindle-shape and well-spread attached morphology **Differentiation:** ALP activity and Von Kossa staining(3-4 w): -Both cells showed similar osteogenic differentiation.
Yamaza T et al.,(2010)	-SHED from exfoliated incisors	Differentiation assessment:	**Flow cytometry(P 3)(%):** STRO-1 CD146	**Proliferation/viability:** CFU (10 d), BrdU (18 h) and RT-PCR for telomerase activity

	-BMSCs from iliac bone	OM supplemented with inorganic phosphate to induce mineralization P: 3	-SHED: 12.06 - SHED:48.39 -BMSCs: 8.36 - BMSCs:31.19 SSEA-4 CD73 -SHED: 85.40 - SHED:91.93 -BMSCs: 80.64 - BMSCs:88.1 CD105 CD166 -SHED: 6.77 - SHED:63.65 -BMSCs: 13.2 - BMSCs:74.93 CD34 CD45 -SHED: 0 - SHED: 0 -BMSCs: 0.2 - BMSCs:0.5	assay: -SHED > BMSCs **Differentiation:** ALP activity(1 w): -SHED ≅ BMSCs with a slight priority of SHED in OM and control medium Western blot analysis(1 w): -SHED was similar to BMSCs in expression of elevated levels of ALP, Runx2, DSP, and OCN markers. Alizarin red staining(mineralized area/total area)(4 w): -SHED ≅ BMSCs
Hsieh JY et al., (2010)	-WJSCs of umbilical cord -BMSCs	Differentiation assessment: OM / DMEM+10% FBS P: 0-7	**Flow cytometry:** BMSCs, WJSCs: CD29, CD73, CD44: + CD14, CD34, CD45: -	**Proliferation/viability:** Cell count(0-20 d): -WJSCs> BMSCs Population doubling time(0-20 d): -WJSCs> BMSCs **Differentiation:** ALP activity(0, 1, 2, 3, 4 w): -BMSCs> WJSCs Von Kossa staining(0, 1, 2, 3, 4 w): -Bone nodules were detectable in BMSCs after 3 weeks but did not observed in WJSCs even after 4 weeks. RT-PCR: Osteogenic-related genes: DMEM+10% FBS: Runx2, OPN: BMSCs> WJSCs OM: ALP, OPN, Runx2: BMSCs>WJSCs Growth related-genes: WJSCs> BMSCs Neurogenesis related-genes: WJSCs> BMSCs Immune response related-genes: BMSCs> WJSCs
Choudhery MS et al.,(2013)	-ASCs were obtained from liposuction procedure during a cosmetic surgery -UCSCs	Differentiation assessment: OM P: Proliferation analysis: 1 Differentiation analysis: 2	**Flow cytometry(%)**(P 1): CD44 CD73 -ASCs: 99.5 - ASCs: 98.9 -UCSCs: 99.1 - UCSCs: 99.2 CD90 CD105 -ASCs: 98.3 - ASCs: 99.4 -UCSCs: 99.4 - UCSCs: 96.5 CD3 CD14/34 -ASCs: 2.7 -ASCs: 0.1 -UCSCs: 1.3 - UCSCs: 0.1 CD19 CD45 -ASCs: 2.5 -ASCs: 0.1 -UCSCs: 2.3 - UCSCs: 0.1	**Proliferation/viability:** CFU assay(14 d): -UCSCs: 69.0 ± 4.8 -ASCs: 96.1 ± 3.1 Population doubling time(d): -ASCs: 2.7 ± 0.03 -UCSCs: 2.0 ± 0.04 Number of cells at saturation density(initial seeding=25,000)(0-20 d): -ASCs: 745,200 ± 28,940 -UCSCs: 836,513 ± 21,063 **Morphology/attachment:** -P 2: Similar homogeneous population of cells with identical fibroblastic morphology observed for both cell types. -P 10: UCSCs showed more changes in morphology and the proliferative potential of these cells reduced more rapidly than ASCs. **Differentiation (3 w)** Von Kossa staining(%positive area): -ASCs: 22.1 ± 1.6 -UCSCs: 13.5 ± 3.2 RT-PCR: ALP: ASCs ≅ UCSCs OCN: ASCs> UCSCs Immunofluorescence (DAPI) staining(%ON positive cells): -ASCs: 60.0 ± 7.6 -UCSCs: 47.6 ± 12.6
Ogata Y et al.,(2015)	-BMSCs obtained during total knee arthroplasty surgery -SySCs obtained during total knee arthroplasty surgery	Proliferation assessment: Culture medium with calcium- and magnesium-free Hank's Balanced	**Flow cytometry(%):** P 3: CD31: -BMSCs:0.03±0.01 - SySCs:0.21±0.14 CD45	**Proliferation/viability**: CFU assay(2-7 w)(isolated THY-1+ and THY-1- cells from BM and Sy were assessed for proliferation) -THY-1+ > THY-1- -THY-1+, LNGFR+> THY-1+, LNGFR- > THY-1-, LNGFR+> THY-1-, LNGFR-

		Salt Solution (HBSS) supplemented with FBS, HEPES and penicillin/streptomycin. Differentiation assessment: OM Ps for flow cytometry assay:3,5 P for differentiation assay:3	-BMSCs:0.03±0.03 SySCs:0.03±0.01 LNGFR -BMSCs:0.03±0.04 SySCs:0.13±0.16 THY-1 -BMSCs:88.3±3.06 SySCs:62.0±6.52 P 5: CD29: -BMSCs:98.0±1.36 SySCs:97.8±0.12 CD44: -BMSCs: 97.7±0.92 SySCs:95.1±3.72 CD105: -BMSCs: 94.6±3.19 SySCs:97.2±0.45 CD166: -BMSCs: 96.9±1.78 SySCs:97.5±1.14 THY-1: -BMSCs: 98.0±0.98 SySCs:95.1±0.21	**Differentiation** RT-PCR(14 d) -Runx2 and OCN to β- actin: SySCs < BMSCs (less than 3-fold) Alizarin red staining(14 d) -SySCs < BMSCs -Chondrogenic capacity assessed by Toluidine blue and Safranin O staining: SySCs > BMSCs
Gao X et al., (2015)	-Human SMSC from skeletal muscle biopsies -Human BMSCs from bone marrow of the femoral heads	Proliferation assessment: -SMSCs medium: high glucose DMEM +20%FBS+ chicken embryo extract+ penicillin/streptomycin -BMSCs medium: α-MEM+10%FBS+antibioticantimycotic+FGF2 Cells were transduced with lenti-viral-BMP2 construct -SMSCs: at P 8 -BMSCs: at P 2		**Differentiation(after 4 w)** MicroCT (mineralized pellet volumes(mm^2)):(3, 4 w) - Non-transduced BMSCs< transduced BMSCs - Non-transduced SMSCs < transduced SMSCs ALP activity -ALP + rates were different in cells obtained from various donors -A very small % of SMSCs and BMSCs showed ALP activity -BMP2 transduction affected the ALP activity positively/negatively RT-PCR BMPR2: SMSCs ≅ BMSCs BMPR1b: SMSCs< BMSCs SOX-9: BMSCs> SMSCs COX-2: transduced cells showed higher COX-2 expression -Lenti-viral BMP2 transduction had no + effect on SOX 9, BMPR2, BMPR1b expression -The BMSCs could be cultured up to P 10 and the SMSCs up to P 20 without any considerable phenotype change. Von Kossa staining: -BMSCs: Untransduced: mineralization mainly at the periphery of the pellets. Transduced: mineralization in both periphery & center of the pellets -SMSCs : Untransduced: mineralization throughout the entire pellet Transduced: increased extent of mineralization OCN IHC: BMSCs and SMSCs expressed OCN in the same location of Von Kossa stained parts.
Rui, YF et al.,(2012)	-TSCs isolated from the midsubstance of rat patellar tendons -BMSCs isolated from rat bone marrow of tibiae and femurs	Differentiation assessment: Culture medium ± BMP-2/ OM P: 3	-	**Differentiation:** ALP activity(3 d): -Without and with BMP-2: TSCs> BMSCs -BMP-2 enhanced ALP activity in TSCs but not in BMSCs. Alizarin red staining(10 d): -Without and with BMP-2: TSCs> BMSCs -BMP-2 enhanced calcium formation significantly in TSCs and less in BMSCs. RT-PCR: BMPR-IA, BMPR-II: TSCs> BMSCs BMPR-IB: TSCs> BMSCs with no significant difference Western blot analysis: -BMPR-IA, BMPR-IB, BMPRII: TSCs> BMSCs
Van Gastel N et al., (2012)	-PDCs of diaphyseal bone from femurs and tibias of adult mice	Differentiation assessment: OM	**Flow cytometry(P 1)** -PDC: CD105:50.6 ± 1.5 CD90:50.5± 8.1	**Proliferation/viability:** Cell count and Growth curves(0-14 d) -PDC > BMSC > TOB Population doubling time(h):

	-TOBs of murine -BMSCs		CD51:73.5±4.9 Sca-1:48.1±9.9 CD73:58.8±4.9 CD11b:3.0±0.7 CD45:3.2±1.2 CD31:1.9±0.5 CD34:3.5±0.4 VEGFR-2:0.8±0.3 -PDC cells expressing hematopoietic or endothelial markers reduced to <1% by P 3. -Regarding the Sca-1$^+$ CD45$^-$ cells, peroisteum showed higher amount of MSCs compared to the bone marrow stroma.	-TOB > BMSC ≅ PDC CFU assay: -Sca-1$^+$CD45$^-$ fraction of the periosteum showed higher colonies than Sca-1$^-$CD45$^-$. **Differentiation(14, 21 d)** ALP activity(14 d): -ALP activity of PDC was upregulated from day 0 to day 14. Alizarin red staining(21 d) -Mineralized nodules were observed in PDC. RT-PCR(0, 21 d) -Runx 2, osterix, Col1a1, OCN: TOB > PDC -Osterix, OPN, OCN:PDC d 21> PDC d 0
Guillot PV et al. (2008)	-f blood -f liver -f BM -Human adult BMSCs	Differentiation assessment: OM		**Differentiation(21 d):** Calcium content(Quantitative analysis of mineral formation): -f BM>f blood>f liver> BMSC RT-PCR: -OCN, BMP2: f BM>f liver>f blood> BMSC -ON, PCE, IGFII, Col1: f blood> f liver> f BM> BMSC -BSP, OPN, Met2A, OPG, PHOS1, SORT, ALP, CBFA1, OSX, NOG: f BM>f blood >f liver > BMSC Von Kossa staining: Highest: f BM
Liu W et al., (2013)	-PDLSCs from the middle third of the root surface of orthodontically extracted teeth -BMSCs	Differentiation assessment: OM Cells were also cultured in OM+ TNF-α P :2-4 TNF-α showed inhibitory effect on cell differentiation of both sources but PDLSCs were more sensitive.	**Flow cytometry(%):** CD90: -PDLSCs:99.9 -BMSCs:98.6 CD105: -PDLSCs:99.3 -BMSCs:99.8 CD146: STRO-1: -PDLSCs:86.6 -BMSCs:78.1 PDLSCs:24.2 -BMSCs:36.6 CD14: -PDLSCs:5.4 -BMSCs:6.2 CD31: -PDLSCs:3.4 -BMSCs:6.9	**Proliferation/viability:** CFU assay: -PDLSCs and BMSCs showed similar niches of cells and colonies. MTT assay, EDU assay , DNA content(7 d): -No significant difference observed in terms of proliferation assays **Differentiation:** **Analysis without TNF-α under osteogenic induction** ALP activity(7 d), Alizarin Red staining, calcium content (14 d): -BMSCs> PDLSCs RT-PCR(7 d): -ALP, RUNX2: BMSCs> PDLSCs **Analysis in OM with/without TNF-α** ALP activity(7 d): -BMSCs> PDLSCs> BMSCs+ TNF-α> PDLSCs+ TNF-α Alizarin red staining, calcium content(14 d): -BMSCs> BMSCs+ TNF-α> PDLSCs> PDLSCs+ TNF-α RT-PCR(7 d): ALP, RUNX2: BMSCs>BMSCs+ TNF-α>PDLSCs> PDLSCs+ TNF-α
Raynaud. C.M et al., (2012)	-Pl-MSCs -Mb-MSCs -BMSCs	Differentiation assessment: DMEM, FCS, Dex, L-ascorbic acid-2-phosphate, β-glycerol phosphate disodium salt pentahydrate inorganic (sodium) phosphate -Osteoactivin was also added to medium for osteogenesis stimulation P: 4	**Flow cytometry(%):** CD90: BMSCs: 97.6 Mb-MSCs: 87.6 Pl-MSCs: 91.1 CD29: BMSCs: 90.9 Mb-MSCs: 99.8 Pl-MSCs: 99.8 CD105: BMSCs: 99.7 Mb-MSCs: 96.7 Pl-MSCs: 99.2 CD73: BMSCs: 98.7 Mb-MSCs: 99.8 Pl-MSCs: 99.5 -The number of MSCs isolated from the membrane was higher than placenta. (15.67% vs. 2.14%)	**Proliferation/viability:** Cell count(24, 48, 72 h): -Mb-MSCs ≅ Pl-MSCs > BMSCs at same Ps of 5, 10, 15. -Mb-MSCs and Pl-MSCs cultured to P 15 without morphology changes or proliferation reduction. While, BMSC discontinued proliferating after Ps 7 to 8. **Differentiation:** Alizarin red staining without osteoactivin(21 d): -Mb-MSCs ≅ BMSCs Alizarin red staining with osteoactivin(7, 14, 21 d) data is presented for d 21: -Addition of osteoactivin increased the osteogenic differentiation of Mb-MSCs and BMSCs. -Mb-MSCs > BMSCs

Amini AR et al., (2012)	-BMSCs from NZW rabbits -BM-EPCs -PB-EPCs	Differentiation assessment: -Cells were analyzed by co-culture with BMSCs from rabbits or alone in blend of osteogenic and angiogenic medium -Cells were assessed in 2D and 3D Matrigel culture	**Flow Cytometry:** CD31: -PB-EPC:+ -BM-EPC:- CD34,CD45: -PB-EPCs, BM-EPCs: low + -BMSC:- CD44: -BMSC:+	**Morphology/attachment:** SEM: - PB-EPC: spindle-shape cells that formed cobblestone colonies after 2-3 weeks the same as human umbilical vein endothelial cells - BM-EPC: spindle-shape cells formed colonies with these cells **Differentiation:** RT-PCR(4 d): BMP-2:MSCs> PB-EPCs> BM-EPCs Col I: MSCs≅ PB-EPCs> BM-EPCs BMP-4: PB-EPCs>MSCs> BM-EPCs BMP-2, Col I,BMP-4: PB-EPC+MSC> BM-EPC+MSC -BMP-2 and BMP-4 expression of both cells increased as the fraction of the co-cultured MSCs increased. This behavior was not observed for Col I expression. ALP activity(14 d): -MSCs> PB-EPCs > BM-EPCs -PB-EPC+MSC>BM-EPC+MSC -Increasing MSC fraction of the co-culture enhanced ALP activity in PB-EPC, but did not affect BM-EPC
Lee SY et al., (2007)	-Human HCs from patients suffering isolated anterior cruciate ligament injuries -BMSCs	Differentiation assessment: OM P: Proliferative assay:0-10 Differentiation assay:1-3	**Flow cytometry**(P 0)**:** CD29 -HCs: 80.1±21.8 BMSCs: 89.5±11.7 CD44 -HCs:86.9±11.4 BMSCs: 86.9±11.9 CD105 -HCs:68.7±32.3 BMSCs:85.4±12.5 CD166 -HCs:20.7±5.2 BMSCs:62.0±18.3 CD14 -HCs: 0.9±0.6 BMSCs: 0.8±0.5 CD34 -HCs: 3.7±2.9 BMSCs: 0.5±0.2 CD45 -HCs: 0.9 ±0.4 BMSCs:1.8 ±0.1	**Proliferation/viability:** CFU assay(colonies per million MNCs)(14 d): -HCs: 5.7 ±1.3 -BMSCs:23.3 ±4.8 **Morphology/attachment:** Phase contrast microscope: -HCs displayed a fibroblast-like spindle shape morphology and form visible colonies around day 5.after 3-4 weeks cells formed a monolayer of fibroblastoid cells. -BMSCs colonies were similar to colony-forming unit-fibroblasts of HCs. **Differentiation:** Alizarin red staining(21 d): -Both cells formed mineralized matrix in OM while there was no evidence of mineralized matrix in original medium. RT-PCR(3 w): -Both cells showed osteogenic potential by expressions of ALP, OCN, OPN, and BSP in OM.
Yang H et al.,(2013)	-Human GMSCs from gingival tissues surrounding the tooth sockets of extracted third molars -Human PDLSCs from periodontal ligament of extracted third molars	Differentiation assessment: OM± TNF-α and interleukin IL-1b	**Flow cytometry(%):** CD45: GMSCs= 1.9 PDLSCs= 0.8 CD 31: GMSCs= 1.3 PDLSCs= 0.9 CD 29: GMSCs= 100 PDLSCs= 100 CD90: GMSCs= 99.9 PDLSCs= 99.9 CD 105: GMSCs= 97 PDLSCs= 96.5 CD 146: GMSCs= 55.2 PDLSCs= 44.2 CD STRO 1: GMSCs= 16.3 PDLSCs= 16.6	**Proliferation/viability** CFU assay (14 d) -GMSCs >PDLSCs MTT assay: (3 d) -d 1,2: GMSCs ≅PDLSCs -d 3: GMSCs > PDLSCs **Differentiation (P4)** ALP activity With or without TNF- α and interleukin IL-1b -PDLSCs > GMSCs Alizarin red staining (4 w) -PDLSCs > GMSCs RT-PCR (10 d) With or without TNF- α and interleukin IL-1b OCN: PDLSCs > GMSCs Runx2: PDLSCs > GMSCs Col 1: PDLSCs > GMSCs
Chadipiralla K et al. (2010)	-PDLSCs	Cultured cells were treated with	-	**Proliferation/viability:** MTS assay(5 d):

	-SHED from pulp of human exfoliated deciduous teeth	basic serum-free medium either alone(control) or supplemented with RA or Dex by given concentrations: -1, 10 and 100 nM Dex -0.5, 1, and 2 μM RA		-PDLSCs and SHEDs: control>1 nM Dex>0.5, 1, 2 μM RA> 10 nM Dex>100 nM Dex -In contrast to RA treatment, Dex inhibited cell proliferation in a dose-dependent manner. - PDLSCs> SHEDs under RA &. PDLSCs≅ SHEDs by Dex treatment **Differentiation:** ALP activity(7, 14 d): - PDLSCs and SHEDs: 2 μM RA> 1 μM RA >0.5 μM RA>1, 10, 100 nM Dex> control - PDLSCs< SHEDs under RA &. PDLSCs≅ SHEDs by Dex treatment Alizarin red staining and Von kossa staining (3, 4 w): -PDLSCs and SHEDs: RA treated groups>control and detected after 3 weeks while Dex groups deposition recognized after 4 weeks. -PDLSCs> SHEDs after RA treatment RT-PCR(7 d): - SHED :RA treatment: Dex treatment: ALP, Runx2, OPN upregulated Runx2 upregulated ON:not affected ALP,OPN,ON not affected Col I downregulated Col I downrwgulated -PDLSC: RA treatment: Dex treatment: ALP upregulated ALP,Runx2, OPN not affected Runx2, OPN,ON not affected ON not affected ColI downregulated ColI downrwgulated -ALP expression: PDLSCs< SHEDs under RA&. PDLSCs≅ SHEDs by Dex treatment Western blot analysis(7 d): PDLSCs and SHEDs: Runx2, OPN production was promoted by RA and Dex treatments.
Yu s et al.,(2012)	-PDLSCs derived from periodontal ligament in the middle one third of the roots of extracted human third molars -WJSCs derived from the umbilical cord	Differentiation assessment: OM or control medium P:3-5	**Flow cytometry:** CD73, CD90, CD105: -WJSCs, PDLSCs:+ CD45,CD34,CD19,CD11b, HLA-DR: -WJSCs, PDLSCs:-	**Proliferation/viability:** Cell number(3, 5, 7 d): -WJSCs> PDLSCs Cell growth curve: - WJSCs proliferated faster than PDLSCs. Population doubling time(h): - WJSCs: 22.23 - PDLSCs: 27.51 **Differentiation:** ALP activity(0, 3, 5, 7 d) and Alizarin red staining(2, 3 w): - PDLSCs> WJSCs in control and OM Calcium content(ng)(0, 2, 3 w): -OM: PDLSCs> WJSCs -Control medium: PDLSCs ≅ WJSCs ≅ 0 RT-PCR(0, 1, 2, 3 w): Osterix, BSP: PDLSCs> WJSCs OPN: WJSCs> PDLSCs OCN, Runx2: PDLSCs ≅ WJSCs -Expression level of RNAs in control medium was lower and approximately consistent to data in OM.
Okumachi E et al.,(2014)	-Rat TA- MSCs (TA; fast muscle) -Rat SO- MSCs (SO; slow muscle)	Differentiation assessment: OM	**Flow cytometry(%):** CD44: TA- MSCs= 94.1±3.0 SO- MSCs= 93.5±1.1 CD90: TA- MSCs= 98.5±0.3 SO- MSCs= 95.5±0.6 CD 29: TA- MSCs = 97.0±0.5 SO- MSCs = 87.8±4.8 CD34: TA- MSCs= 0.2±0.0 SO- MSCs= 0.3±0.2 CD45: TA- MSCs= 0.1±0.1 SO- MSCs= 0.1±0.0	**Proliferation/viability (P 11)** CFU assay (Colony number per 10^4 cells) -TA- MSCs : 48.1±9.8 -SO- MSCs :94.3±19 CFU assay (Colony number per volume (mg)) - TA- MSCs :4.4±0.6 - SO- MSCs :24.6±10.5 **Differentiation**: Alizarin red Staining (28 d) -Mineralization observed in both cells with rich calcium deposits. RT-PCR(7, 14, 21 d) d 7: Runx2: TA- MSCs > SO- MSCs ALP: TA- MSCs > SO- MSCs OPN: TA- MSCs > SO- MSCs d14: Runx2: TA- MSCs > SO- MSCs ALP: TA- MSCs > SO- MSCs OPN: TA- MSCs > SO- MSCs d21:

			CD 11b: TA- MSCs= 1.1±0.5 SO- MSCs= 0.2±0.1	Runx2: TA- MSCs > SO- MSCs ALP: TA- MSCs > SO- MSCs OPN: TA- MSCs = SO- MSCs
Takahashi K et al.,(2004)	-FPl-MSCs -MPl-MSCs	Differentiation assessment: OM or control medium	-	**Differentiation(3 w):** Von Kossa staining: -FPl-MSCs showed calcium deposition in OM. While, MPl-MSCs cultured in OM and both in control medium did not. Calcium content(μg/μg DNA): -FPl-MSCs in OM ≅200 -MPl-MSCs in OM and FPl-MSCs, MPl-MSCs in control medium ≅0 RT-PCR: (OPN, OCN, ALP, and Col I in control medium) -FPl-MSCs and MPl-MSCs expressed the markers but the expression did not change after 3 weeks of culture.
Abe S et al., (2012)	-APDCs obtained from the tip of the root of developing teeth with immature apex -CPCs obtained from the coronal portion of teeth	Cells were plated on super-hydrophilic plates, and then cultured in DMEM+ bFGF+ EGF+N2. The primary sphere-forming cells were assessed. Differentiation assessment: OM	**Flow cytometry and DAPI:** APDCs: CD105 and CD166:+ Spheres derived from APDCs: -Expression of CD105 reduced and CD166 expression was lost.	**Proliferation/viability:** Sphere-forming capacity(number of spheres≥100μm/wall)(7 d): -APDCs> CPCs **Morphology/attachment:** Phase contrast microscopic photographs: -Both cells showed similar fibroblastic morphology. **Differentiation**: Alizarin red staining: -Sphere-forming cells derived from APDCs differentiated into mineralizing cells.

importance in osteogenesis. Peister followed differentiation capacity of AFSCs and BMSCs on PCL-collagen scaffolds for 3, 5, 10, 15 weeks. He found that although BMSCs have prompt differentiation and earlier mineralized matrix formation, AFSCs showed greater mineralized matrix and calcium content after 15 weeks of culturing (53). The distinct time point of cell differentiation supports the efficacy of co-culturing approaches.

Conclusion

This study showed that the origins of MSCs impel their proliferative and osteogenic sufficiency and thus influence their application as a cell sources for bone tissue engineering. Human BMSCs demonstrated superior osteogenicity and human DPSCs showed the best cell proliferation on the scaffold. Although BMSCs are the best cellular nominee for cell based bone regeneration and most papers support their osteogenic capacity in vitro, assessment of their ability in vivo is of greater clinical value.

Acknowledgement

There is no financial support in this study.

Conflict of Interest: 'None declared'.

References

1. Bourgine PE, Scotti C, Pigeot S, Tchang LA, Todorov A, Martin I. Osteoinductivity of engineered cartilaginous templates devitalized by inducible apoptosis. Proceedings of the National Academy of Sciences. 2014;111(49):17426-31.
2. Cunniffe GM, Vinardell T, Murphy JM, Thompson EM, Matsiko A, O'Brien FJ, et al. Porous decellularized tissue engineered hypertrophic cartilage as a scaffold for large bone defect healing. Acta biomaterialia. 2015;23:82-90.
3. Gawlitta D, Benders KE, Visser J, van der Sar AS, Kempen DH, Theyse LF, et al. Decellularized cartilage-derived matrix as substrate for endochondral bone regeneration. Tissue Engineering Part A. 2014;21(3-4):694-703.
4. Kon E, Muraglia A, Corsi A, Bianco P, Marcacci M, Martin I, et al. Autologous bone marrow stromal cells loaded onto porous hydroxyapatite ceramic accelerate bone repair in critical-size defects of sheep long bones. Journal of biomedical materials research. 2000;49(3):328-37.
5. Bruder SP, Kraus KH, Goldberg VM, Kadiyala S. The effect of implants loaded with autologous mesenchymal stem cells on the healing of canine segmental bone defects. JBJS. 1998;80(7):985-96.
6. Hosseinpour S, Ahsaie MG, Rad MR, taghi Baghani M, Motamedian SR, Khojasteh A. Application of selected scaffolds for bone tissue engineering: a systematic review. Oral and maxillofacial surgery. 2017;21(2):109-29.
7. Mosna F, Sensebé L, Krampera M. Human bone marrow and adipose tissue mesenchymal stem cells: a user's guide. Stem cells and development. 2010;19(10):1449-70.

8. Rezai-Rad M, Bova JF, Orooji M, Pepping J, Qureshi A, Del Piero F, et al. Evaluation of bone regeneration potential of dental follicle stem cells for treatment of craniofacial defects. Cytotherapy. 2015;17(11):1572-81.
9. Gimble J, Rad MR, Yao S. Adipose tissue–derived stem cells and their regeneration potential. Stem Cells in Craniofacial Development and Regeneration. 2013:241-58.
10. Khojasteh A, Nazeman P, Rad MR. Dental stem cells in oral, maxillofacial and craniofacial regeneration. Dental Stem Cells: Springer; 2016. p. 143-65.
11. Janicki P, Kasten P, Kleinschmidt K, Luginbuehl R, Richter W. Chondrogenic pre-induction of human mesenchymal stem cells on β-TCP: enhanced bone quality by endochondral heterotopic bone formation. Acta biomaterialia. 2010;6(8):3292-301.
12. Feng W, Lv S, Cui J, Han X, Du J, Sun J, et al. Histochemical examination of adipose derived stem cells combined with β-TCP for bone defects restoration under systemic administration of 1α, 25 (OH) 2D3. Materials Science and Engineering: C. 2015;54:133-41.
13. Morad G, Kheiri L, Khojasteh A. Dental pulp stem cells for in vivo bone regeneration: a systematic review of literature. Archives of oral biology. 2013;58(12):1818-27.
14. Motamedian SR, Hosseinpour S, Ahsaie MG, Khojasteh A. Smart scaffolds in bone tissue engineering: A systematic review of literature. World journal of stem cells. 2015;7(3):657.
15. Salehi-Nik N, Rezai Rad M, Kheiri L, Nazeman P, Nadjmi N, Khojasteh A. Buccal fat pad as a potential source of stem cells for bone regeneration: a literature review. Stem cells international. 2017;2017.
16. Rezai Rad M, Bohloli M, Akhavan Rahnama M, Anbarlou A, Nazeman P, Khojasteh A. Impact of Tissue Harvesting Sites on the Cellular Behaviors of Adipose-Derived Stem Cells: Implication for Bone Tissue Engineering. Stem Cells International. 2017;2017.
17. Shafiq M, Jung Y, Kim SH. Insight on stem cell preconditioning and instructive biomaterials to enhance cell adhesion, retention, and engraftment for tissue repair. Biomaterials. 2016;90:85-115.
18. Liang Y, Wen L, Shang F, Wu J, Sui K, Ding Y. Endothelial progenitors enhanced the osteogenic capacities of mesenchymal stem cells in vitro and in a rat alveolar bone defect model. Archives of oral biology. 2016;68:123-30.
19. Via AG, Frizziero A, Oliva F. Biological properties of mesenchymal Stem Cells from different sources. Muscles, ligaments and tendons journal. 2012;2(3):154.
20. Chen Y, Huang AH, Chan AW, Lin L. Human dental pulp stem cells derived from cryopreserved dental pulp tissues of vital extracted teeth with disease demonstrate hepatic-like differentiation. Journal of tissue engineering and regenerative medicine. 2016;10(6):475-85.
21. Matarasso A. Buccal fat pad excision: aesthetic improvement of the midface. Annals of plastic surgery. 1991;26(5):413-8.
22. Niada S, Ferreira LM, Arrigoni E, Addis A, Campagnol M, Broccaioli E, et al. Porcine adipose-derived stem cells from buccal fat pad and subcutaneous adipose tissue for future preclinical studies in oral surgery. Stem cell research & therapy. 2013;4(6):148.
23. Weinand C, Xu JW, Peretti GM, Bonassar LJ, Gill TJ. Conditions affecting cell seeding onto three-dimensional scaffolds for cellular-based biodegradable implants. Journal of Biomedical Materials Research Part B: Applied Biomaterials. 2009;91(1):80-7.
24. Gregory CA, Gunn WG, Peister A, Prockop DJ. An Alizarin red-based assay of mineralization by adherent cells in culture: comparison with cetylpyridinium chloride extraction. Analytical biochemistry. 2004;329(1):77-84.
25. Rodrigues MT, Lee SJ, Gomes ME, Reis RL, Atala A, Yoo JJ. Amniotic fluid-derived stem cells as a cell source for bone tissue engineering. Tissue Engineering Part A. 2012;18(23-24):2518-27.
26. Bhumiratana S, Grayson WL, Castaneda A, Rockwood DN, Gil ES, Kaplan DL, et al. Nucleation and growth of mineralized bone matrix on silk-hydroxyapatite composite scaffolds. Biomaterials. 2011;32(11):2812-20.
27. Shafiee A, Seyedjafari E, Soleimani M, Ahmadbeigi N, Dinarvand P, Ghaemi N. A comparison between osteogenic differentiation of human unrestricted somatic stem cells and mesenchymal stem cells from bone marrow and adipose tissue. Biotechnology letters. 2011;33(6):1257-64.
28. De Ugarte DA, Morizono K, Elbarbary A, Alfonso Z, Zuk PA, Zhu M, et al. Comparison of multi-lineage cells from human adipose tissue and bone marrow. Cells tissues organs. 2003;174(3):101-9.
29. Aliborzi G, Vahdati A, Mehrabani D, Hosseini SE, Tamadon A. Isolation, characterization and growth kinetic comparison of bone marrow and adipose tissue mesenchymal stem cells of Guinea pig. International journal of stem cells. 2016;9(1):115.
30. Elkhenany H, Amelse L, Caldwell M, Abdelwahed R, Dhar M. Impact of the source and serial passaging of goat mesenchymal stem cells on osteogenic differentiation potential: implications for bone tissue engineering. Journal of animal science and biotechnology. 2016;7(1):16.
31. Izadpanah R, Trygg C, Patel B, Kriedt C, Dufour J, Gimble JM, et al. Biologic properties of mesenchymal stem cells derived from bone marrow and adipose tissue. Journal of cellular biochemistry. 2006;99(5):1285-97.
32. Pierdomenico L, Bonsi L, Calvitti M, Rondelli D, Arpinati M, Chirumbolo G, et al. Multipotent mesenchymal stem cells with immunosuppressive activity can be easily isolated from dental pulp. Transplantation. 2005;80(6):836-42.
33. Rajendran R, Gopal S, Masood H, Vivek P, Deb K. Regenerative potential of dental pulp mesenchymal stem cells harvested from high caries patient's teeth. Journal of stem cells. 2013;8(1):25.
34. Yamaza T, Kentaro A, Chen C, Liu Y, Shi Y, Gronthos S, et al. Immunomodulatory properties of stem cells from human exfoliated deciduous teeth. Stem cell research & therapy. 2010;1(1):5.

35. Alge DL, Zhou D, Adams LL, Wyss BK, Shadday MD, Woods EJ, et al. Donor-matched comparison of dental pulp stem cells and bone marrow-derived mesenchymal stem cells in a rat model. Journal of tissue engineering and regenerative medicine. 2010;4(1):73-81.
36. Ponnaiyan D, Jegadeesan V. Comparison of phenotype and differentiation marker gene expression profiles in human dental pulp and bone marrow mesenchymal stem cells. European journal of dentistry. 2014;8(3):307.
37. Davies O, Cooper P, Shelton R, Smith A, Scheven B. A comparison of the in vitro mineralisation and dentinogenic potential of mesenchymal stem cells derived from adipose tissue, bone marrow and dental pulp. Journal of bone and mineral metabolism. 2015;33(4):371-82.
38. Hsieh J-Y, Fu Y-S, Chang S-J, Tsuang Y-H, Wang H-W. Functional module analysis reveals differential osteogenic and stemness potentials in human mesenchymal stem cells from bone marrow and Wharton's jelly of umbilical cord. Stem cells and development. 2010;19(12):1895-910.
39. Choudhery MS, Badowski M, Muise A, Harris DT. Comparison of human mesenchymal stem cells derived from adipose and cord tissue. Cytotherapy. 2013;15(3):330-43.
40. Jin HJ, Bae YK, Kim M, Kwon S-J, Jeon HB, Choi SJ, et al. Comparative analysis of human mesenchymal stem cells from bone marrow, adipose tissue, and umbilical cord blood as sources of cell therapy. International journal of molecular sciences. 2013;14(9):17986-8001.
41. Raynaud C, Maleki M, Lis R, Ahmed B, Al-Azwani I, Malek J, et al. Comprehensive characterization of mesenchymal stem cells from human placenta and fetal membrane and their response to osteoactivin stimulation. Stem cells international. 2012;2012.
42. Ding D-C, Wu K-C, Chou H-L, Hung W-T, Liu H-W, Chu T-Y. Human infrapatellar fat pad-derived stromal cells have more potent differentiation capacity than other mesenchymal cells and can be enhanced by hyaluronan. Cell transplantation. 2015;24(7):1221-32.
43. Broccaioli E, Niada S, Rasperini G, Ferreira LM, Arrigoni E, Yenagi V, et al. Mesenchymal stem cells from Bichat's fat pad: in vitro comparison with adipose-derived stem cells from subcutaneous tissue. BioResearch open access. 2013;2(2):107-17.
44. Kato T, Hattori K, Deguchi T, Katsube Y, Matsumoto T, Ohgushi H, et al. Osteogenic potential of rat stromal cells derived from periodontal ligament. Journal of tissue engineering and regenerative medicine. 2011;5(10):798-805.
45. Ongaro A, Pellati A, Bagheri L, Fortini C, Setti S, De Mattei M. Pulsed electromagnetic fields stimulate osteogenic differentiation in human bone marrow and adipose tissue derived mesenchymal stem cells. Bioelectromagnetics. 2014;35(6):426-36.
46. Hennig T, Lorenz H, Thiel A, Goetzke K, Dickhut A, Geiger F, et al. Reduced chondrogenic potential of adipose tissue derived stromal cells correlates with an altered TGFβ receptor and BMP profile and is overcome by BMP-6. Journal of cellular physiology. 2007;211(3):682-91.
47. Brocher J, Janicki P, Voltz P, Seebach E, Neumann E, Mueller-Ladner U, et al. Inferior ectopic bone formation of mesenchymal stromal cells from adipose tissue compared to bone marrow: rescue by chondrogenic pre-induction. Stem cell research. 2013;11(3):1393-406.
48. Schneider RK, Puellen A, Kramann R, Raupach K, Bornemann J, Knuechel R, et al. The osteogenic differentiation of adult bone marrow and perinatal umbilical mesenchymal stem cells and matrix remodelling in three-dimensional collagen scaffolds. Biomaterials. 2010;31(3):467-80.
49. Xu H, Zhao L, Weir M. Stem cell-calcium phosphate constructs for bone engineering. Journal of dental research. 2010;89(12):1482-8.
50. Yang H, Gao L-N, An Y, Hu C-H, Jin F, Zhou J, et al. Comparison of mesenchymal stem cells derived from gingival tissue and periodontal ligament in different incubation conditions. Biomaterials. 2013;34(29):7033-47.
51. Chadipiralla K, Yochim JM, Bahuleyan B, Huang C-YC, Garcia-Godoy F, Murray PE, et al. Osteogenic differentiation of stem cells derived from human periodontal ligaments and pulp of human exfoliated deciduous teeth. Cell and tissue research. 2010;340(2):323-33.
52. Rui YF, Lui PPY, Lee YW, Chan KM. Higher BMP receptor expression and BMP-2-induced osteogenic differentiation in tendon-derived stem cells compared with bone-marrow-derived mesenchymal stem cells. International orthopaedics. 2012;36(5):1099-107.
53. Peister A, Woodruff MA, Prince JJ, Gray DP, Hutmacher DW, Guldberg RE. Cell sourcing for bone tissue engineering: amniotic fluid stem cells have a delayed, robust differentiation compared to mesenchymal stem cells. Stem cell research. 2011;7(1):17-27.

Please cite this paper as: Hassan Shahriyari M, Housseinpour S, Paknejad Z, Khojasteh A. Comparative Evaluation of Various Mesenchymal Stem Cells in Combination with B-Tricalcium Phosphate. Regen Reconstr Restor. 2017;2(2):202-219. *Doi: 10.22037/rrr.v2i2.21731.*