

A Novel Set of Serum-Free, Xeno-Free Differentiation Media for Adipogenesis, Osteogenesis And Chondrogenesis of Human Mesenchymal Stem Cells from Various Tissue Sources

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Abstract

Human mesenchymal stem cells (hMSCs) are multipotent adult stem cells that can be isolated from various tissues as well as generated in vitro from hESCs and iPS cells.

hMSCs have at least trilineage differentiation potential in vitro (into fat, bone, and cartilage cells), and it is part of the Minimal Experimental Criteria for MSC proposed by the International Society for Cellular Therapy (ISCT). In addition, differentiation of hMSCs into specific lineage provides the basis for the use of human MSC in cell therapy applications. Either undifferentiated or differentiated, hMSCs can be used for in vivo implantation into damaged tissue sites. The differentiation potential may differ in relation to the culture condition and the source of hMSCs, and it is still unknown which source should be used for each specific disease.

The quality of the culture medium and differentiation media is particularly crucial with regard to therapeutic applications since multipotent hMSCs and differentiated cell properties can be significantly affected by medium components, culture condition, and the manual used for culturing and differentiation.

To date, most of the common differentiation media are composed of FBS and xenogenic compounds, which is a major drawback for both research and clinical applications. Improving the culture conditions and differentiation potential is required for differentiated hMSCs to become the cells of choice for use in modern regenerative medicine and drug screening.

The present study addressed the development of novel serum-free, xeno-free media and supplements that efficiently differentiate hMSCs from various sources into adipocytes, osteoblasts, and chondrocytes. Molecular characterization and functional assays were used to evaluate the quality and purity of the differentiated cells.

This novel SF, XF system enables achieving defined conditions for rapid generation of differentiated hMSCs towards tissue engineering and drug screening applications.

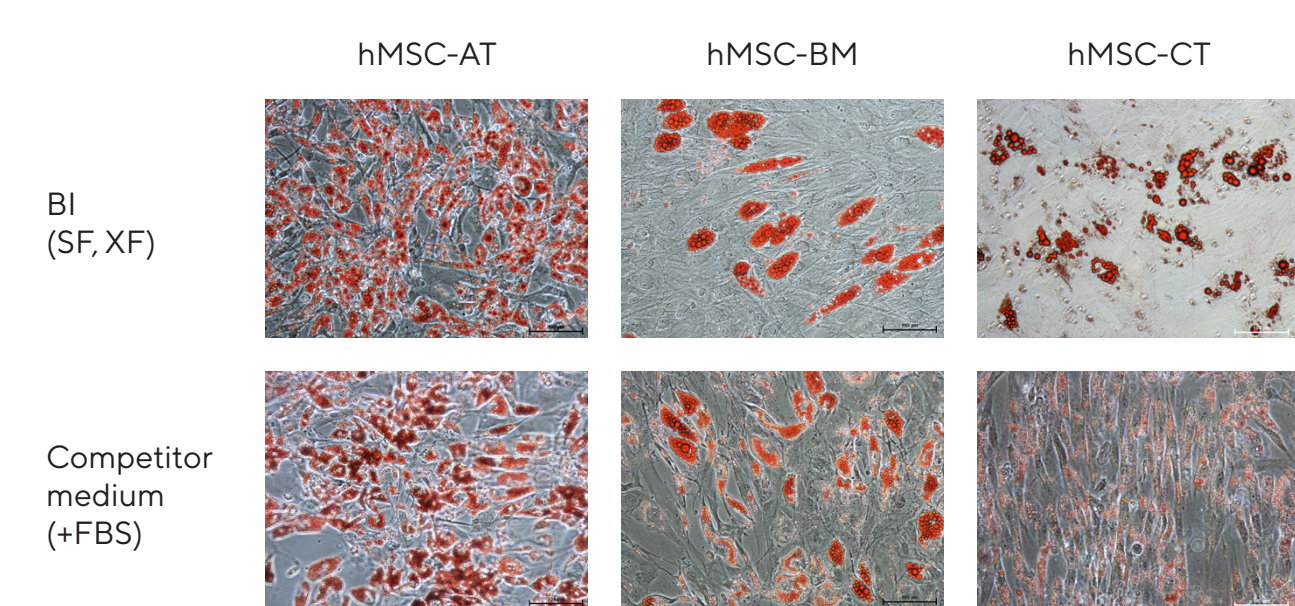
Abbreviations

ACAN	Aggrecan	hMSC-DP	Dental Pulp-derived hMSC
ARS	Alizarin Red S	hMSC-PL	Placenta-derived hMSC
CPC	Cetylpyridinium Chloride	hMSC-WJ	Wharton's Jelly (cord tissue)-derived hMSC
FABP4	Fatty Acid Binding Protein 4	IF	Immunofluorescence
FBS	Fetal Bovine Serum	OCN	Osteocalcin (BGLAP)
GAGs	Glycosaminoglycans	PPARG	Peroxisome Proliferator-Activated Receptor
GuHCl	Guanidine HCL	SF	Serum Free
hMSCs	hMSC Human Mesenchymal Stem Cells	XF	Xeno Free
hMSC-AT	Adipose Tissue-derived hMSC		
hMSC-BM	Bone Marrow-derived hMSC		

Results

I. Adipogenesis

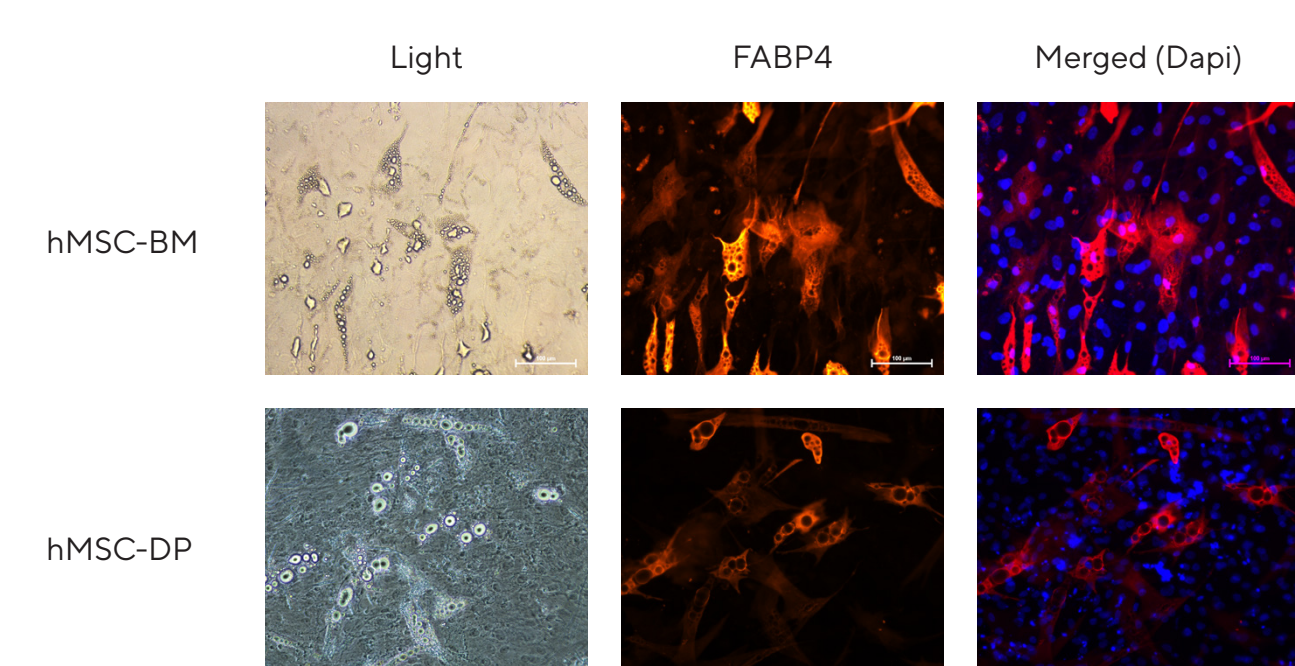
Figure 1: MSCgo™ Adipogenic Is Superior for a Variety of Sources of hMSCs



hMSCs derived from a variety of sources: AT, BM, and CT, seeded in SF, XF culture system (MSC NutriStem® XF and MSC Attachment Solution) for 24 hrs following initiation of adipogenesis using MSCgo™ Adipogenic and commercial medium composed of FBS. Representative images (x200) of stained adipocytes (Oil Red O) after 11 days (hMSC-AT), 14 days (hMSC-BM) and 17 days (hMSC-CT) of adipogenesis assay.

Adipogenesis of hMSCs from various sources is achievable under a SF, XF culture system.

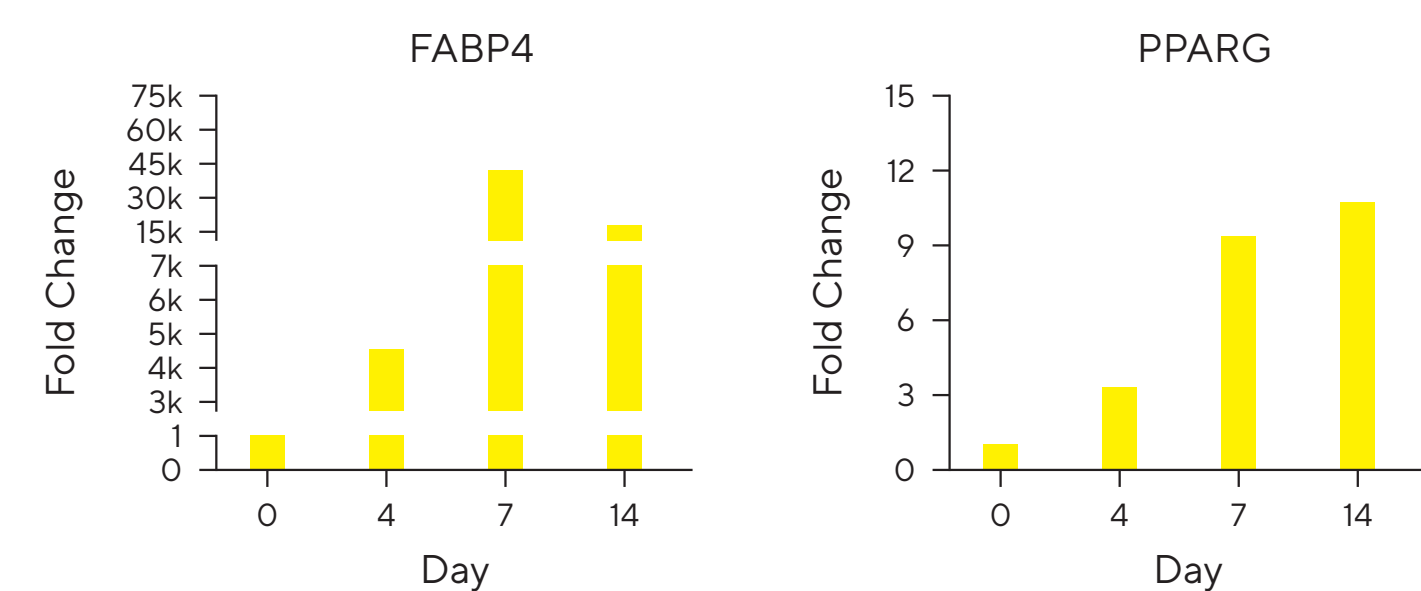
Figure 2: High Expression Level of Mature Adipogenic Marker (IF)



Light microscopic and immunofluorescence staining (FABP4, red), counterstained with DAPI (blue), after 15 days (hMSC-BM) and 24 days (hMSC-DP) of adipogenesis assay in MSCgo™ Adipogenic.

hMSCs differentiated into adipocytes using MSCgo™ Adipogenic Medium exhibit high expression of mature adipogenic markers.

Figure 3: Elevated Expression of Adipocyte Markers During Adipogenesis

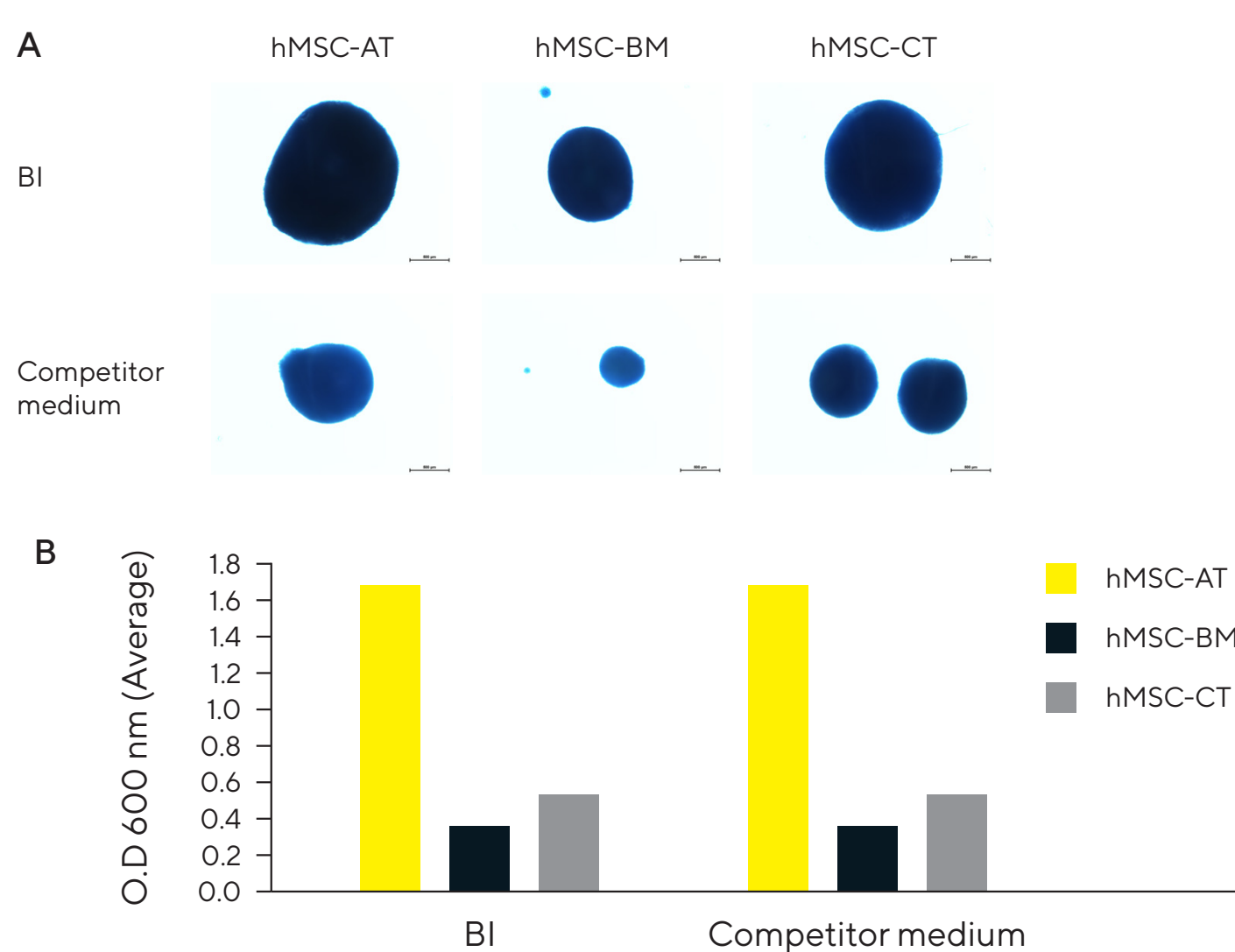


Real-time results of adipogenic differentiated hMSC-AT during adipogenesis assay using MSCgo™ Adipogenic. The results are expressed as a fold-change of expression level according to non-differentiated hMSC-AT (Day 0).

High expression of the adipocyte-related genes is observed during adipogenesis of hMSCs using MSCgo™ Adipogenic.

II. Chondrogenesis

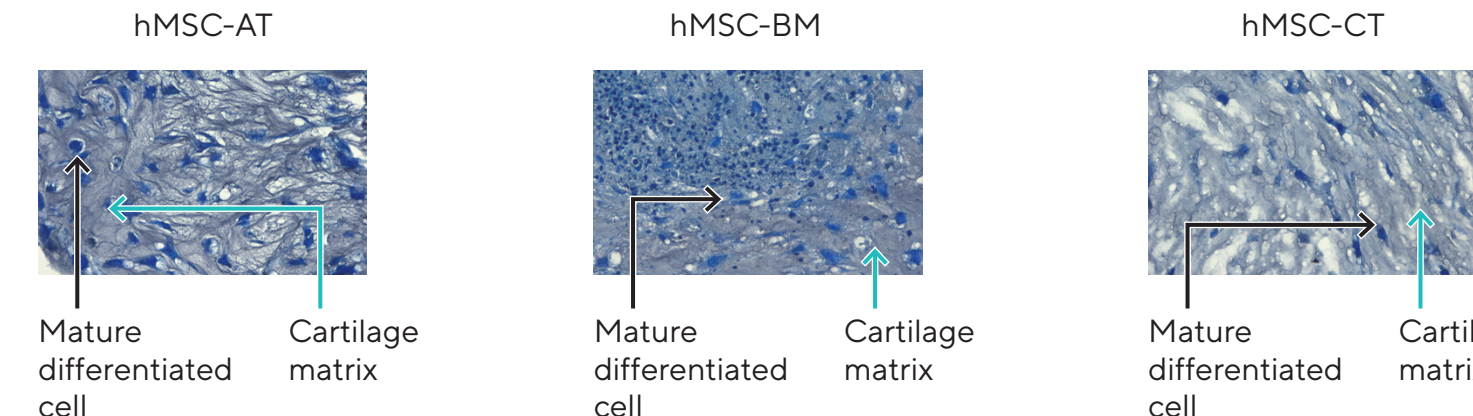
Figure 4: MSCgo™ Adipogenic Is Superior for a Variety of Sources of hMSCs



hMSCs derived from a variety of sources induced to chondrogenesis using MSCgo™ Chondrogenic and commercial medium composed of FBS. A. Representative images (x40) of stained chondrocytes (Alcian Blue) after 21 days of chondrogenesis assay. B. Semi quantitative results for the Alcian Blue intensity staining.

Chondrogenesis of hMSCs from various sources is superior using MSCgo™ Chondrogenic, results in larger cartilage with a higher intensity of stained GAGs in comparison to competitor medium.

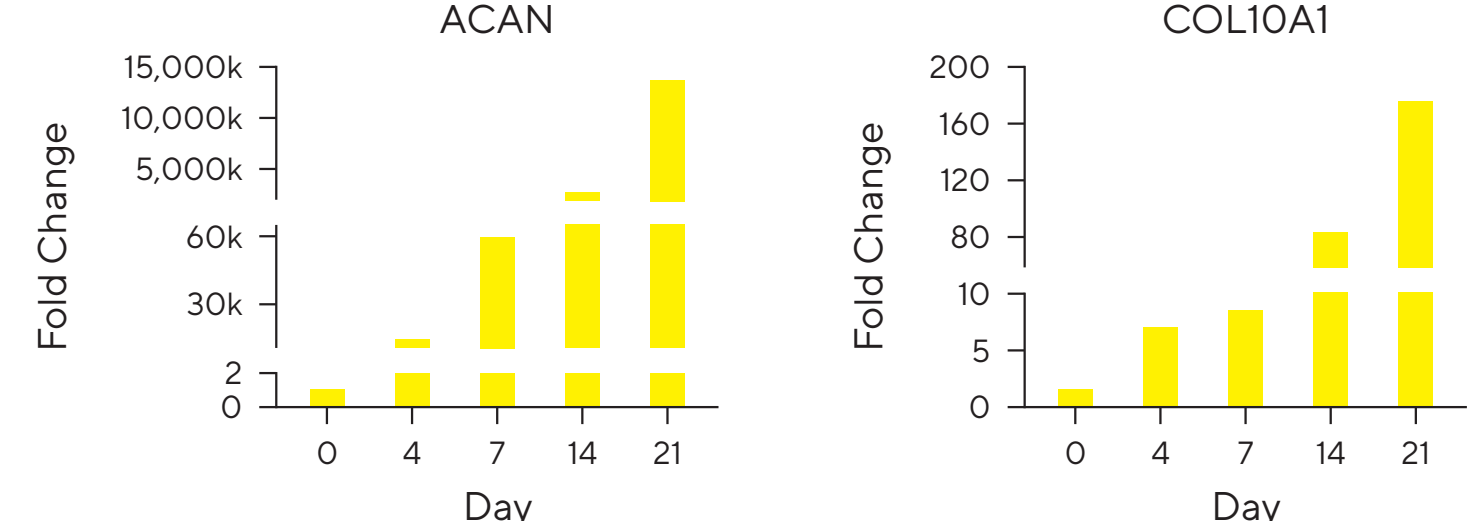
Figure 5: Evaluation of Cartilage Maturation by Histology Examination



Histopathological results of hMSCs from various sources stained with Toluidine Blue after 21-day chondrogenesis assay using MSCgo™ Chondrogenic. The presence of a cartilage matrix and mature hypertrophic chondrocytes (lacunae) are indicated by positive staining of proteoglycans with Toluidine Blue.

MSCgo™ Chondrogenic efficiently induces hMSCs from various sources to differentiate into mature chondrocytes surrounded by cartilage matrix.

Figure 6: Elevated Expression of Chondrocyte Markers During Chondrogenesis of hMSCs



Real-time results of ACAN and collagen type X alpha 1 (COL 10A1) in chondrogenic differentiated hMSC-AT during chondrogenesis assay using MSCgo™ Chondrogenic. The results are expressed as a fold-change of expression level according to non-differentiated hMSC-AT (Day 0).

Elevated expression of the mature chondrocyte-related genes is observed during chondrogenesis of hMSCs using MSCgo™ Adipogenic.

Materials and Methods

Cells

hMSCs from a variety of sources: BM (Lonza, Promocell), AT (ATCC, Promocell), WJ (ATCC, Promocell) and DP (Lonza) were used in this study.

Culture system

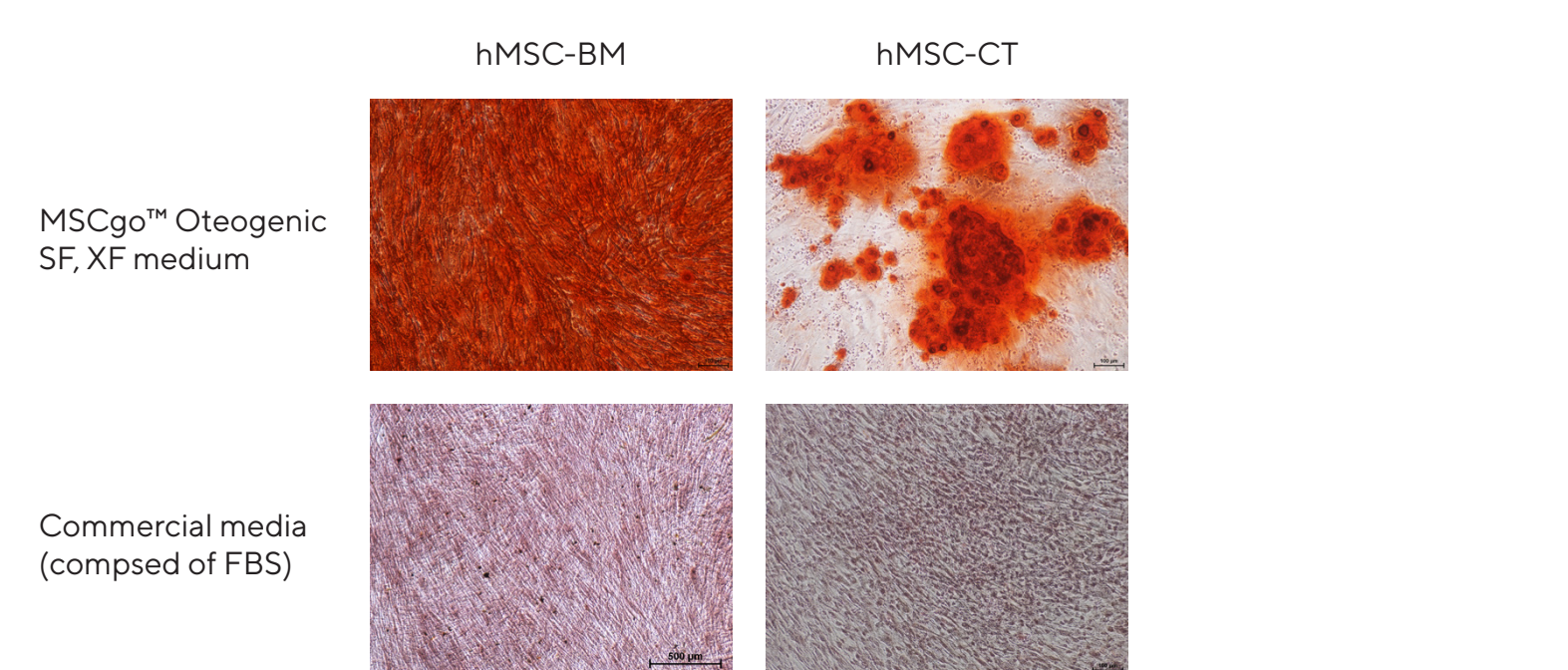
hMSCs were cultured in a SF, XF expansion medium (MSC NutriStem® XF, BI) on pre-coated dishes (MSC Attachment Solution, BI). For expansion, cells were seeded at a concentration of 5,000 viable cells/cm² and harvested using Recombinant Trypsin Solution (BI).

Differentiation Assays

- Adipogenesis and Osteogenesis:** 6×10^4 cells/well were seeded in 24 w/p ($3 - 4 \times 10^4$ cells/cm²) in 0.5 mL/wells of MSC NutriStem® XF, on pre-coated plates (MSC Attachment Solution, BI). The cells were incubated for 24 hrs (37°C , 5% CO_2) to achieve >80% confluence following replacement of the culture medium with MSCgo™ differentiation media (BI) or other desired differentiation media. Medium was changed according to the manufacturer instructions. After 10–24 days assay the cells were fixed for differentiation evaluation.
- Chondrogenesis:** for micromass culture, 1×10^5 cells/well were seeded in 96 w/p U-bottom ULA plates ($3 - 4 \times 10^5$ cells/cm²) in 0.1ml of MSC NutriStem® XF (BI). The cells were incubated for 24 hrs (37°C , 5% CO_2) to achieve spheroids following replacement of the culture medium with MSCgo™ Chondrogenic (BI) or other desired chondrogenic differentiation media. Medium was changed according to the manufacturer instructions. After 14–28 days assay the cells were fixed for differentiation evaluation.

III. Osteogenesis

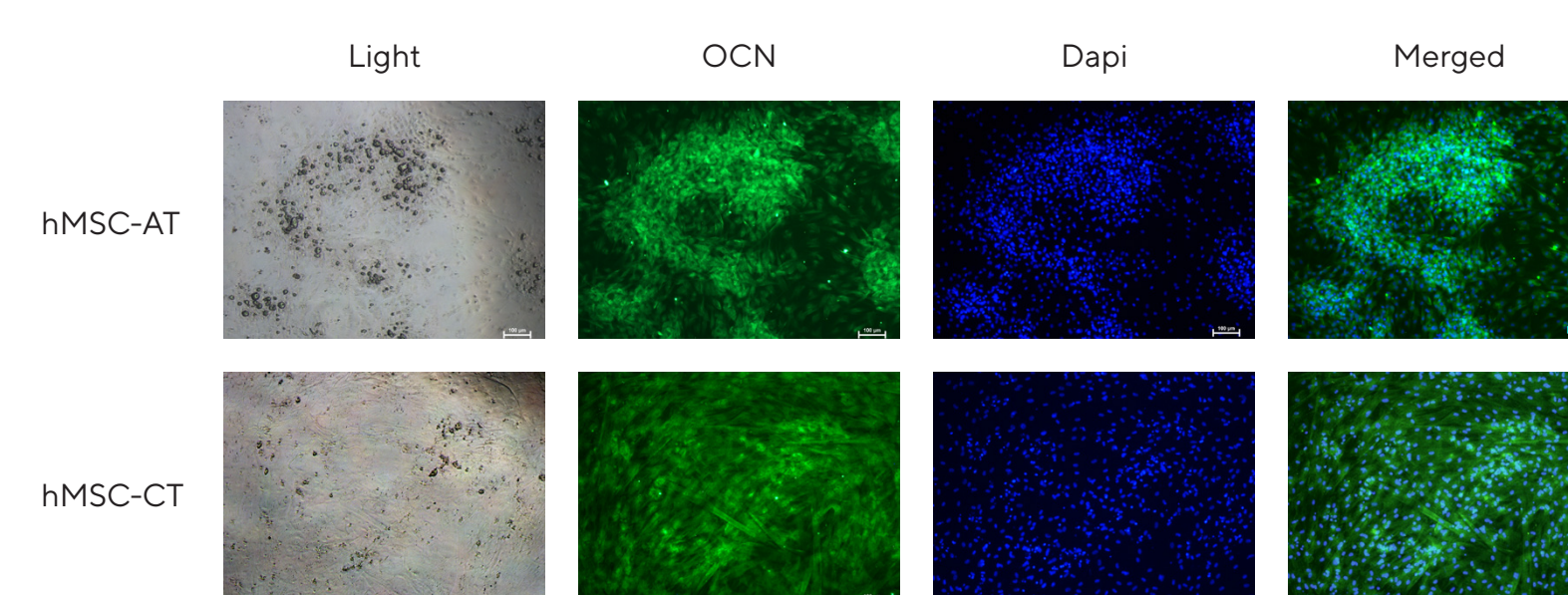
Figure 7: MSCgo™ Osteogenic Is Superior for a Variety of Sources of hMSCs



Representative images (x100) of ARS stained osteocytes after 11 days (hMSC-BM) and 14 days (hMSC-WJ) of osteogenesis assay in MSCgo™ Osteogenic and commercial media composed of FBS.

MSCgo™ Osteogenic is suitable for a variety of hMSC types, whereas different commercial media (composed of FBS) are not.

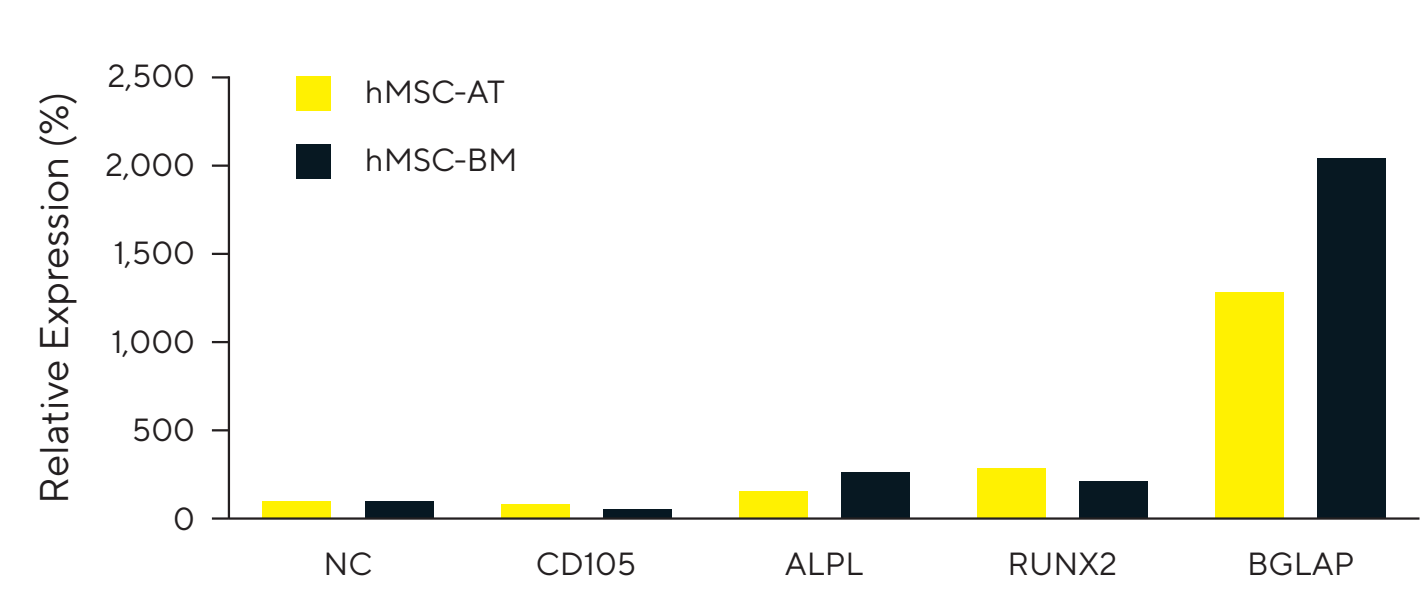
Figure 8: High Expression Level of Mature Osteogenic Markers (IF)



Light microscopic and immunofluorescence staining (OCN, green) of hMSCs, counterstained with DAPI (blue), after 24 days of osteogenesis in MSCgo™ Osteogenic.

hMSCs differentiated into osteocytes using MSCgo™ Osteogenic exhibit calcified culture with high expression of mature osteogenic markers.

Figure 9: Elevated Expression of Mature Osteogenic Markers (RT-PCR)



Relative expression (RT-PCR) of osteocytes markers after 10 days of osteogenesis in MSCgo™ Osteogenic in comparison to un-differentiated hMSCs (Cultured in MSC NutriStem® XF).

Osteogenic markers were upregulated whereas un-differentiated hMSC marker (CD-105) was down regulated using MSCgo™ Osteogenic.

Evaluation of Differentiation

Morphology evaluation was performed for observation of mature adipocytes cells composed of oil droplets (adipogenesis), to detect the formation of mineralized culture with calcified nodules and calcium secretion (osteogenesis) and to evaluate the shape and size of the cartilage-like spheroid structure (chondrogenesis).

Histochemical staining: following differentiation, cells were fixed (4% formaldehyde) and incubated with typical staining solutions:

- Adipogenesis:** 0.2% Oil Red O (Sigma) for 30 min. Positive red staining of oil droplet accumulation in the cells indicates mature adipocytes.
- Osteogenesis:** 2% ARS (Sigma) for 30 min. Positive red staining of calcium indicates mature osteocytes.
- Chondrogenesis:** 1% Alcian Blue (Sigma) for 24 hrs Positive blue staining of proteoglycans indicates mature chondrocytes.

Semi-quantification of staining intensity:

- Adipogenesis:** Oil Red O staining was quantified by eluting the dye in 2-propanol (100%) for 1 hr and measuring absorbance at 550 nm.
- Osteogenesis:** Alizarin Red staining was quantified by eluting the dye in 10% (w/v) cetylpyridinium chloride (CPC) for 1 hr, and measuring absorbance at 550 nm.
- Chondrogenesis:** Alcian Blue staining was quantified by eluting the dye in 6M Guanidine HCL (GuHCl) for 24 hrs ($2 - 8^\circ\text{C}$) and measuring absorbance at 600 nm.

Histopathological Examinations: For assessment of Chondrogenic differentiation, tissue sections at approximately 5 microns thickness were formalin-fixed (4% formaldehyde), paraffin-embedded, and stained with Toluidine blue using routine protocol.

RT-qPCR analyses: total RNA was extracted (ReliaPrep™ RNA Cell Miniprep System, Promega), and reverse transcribed (EZ-First Strand cDNA, BI). Quantitative real-time PCR was performed using TaqMan™ Universal PCR

Master Mix (Applied Biosystems), gene-specific TaqMan PCR probes and FAM primers for matured genes, specific for each cell lineage.

- Adipogenesis:** FABP4 and PPARG.
- Osteogenesis:** RUNX2, SP7, ALP, Osteonectin (SPOCK2), and Osteocalcin (OCN).
- Chondrogenesis:** ACAN and COL10A1.

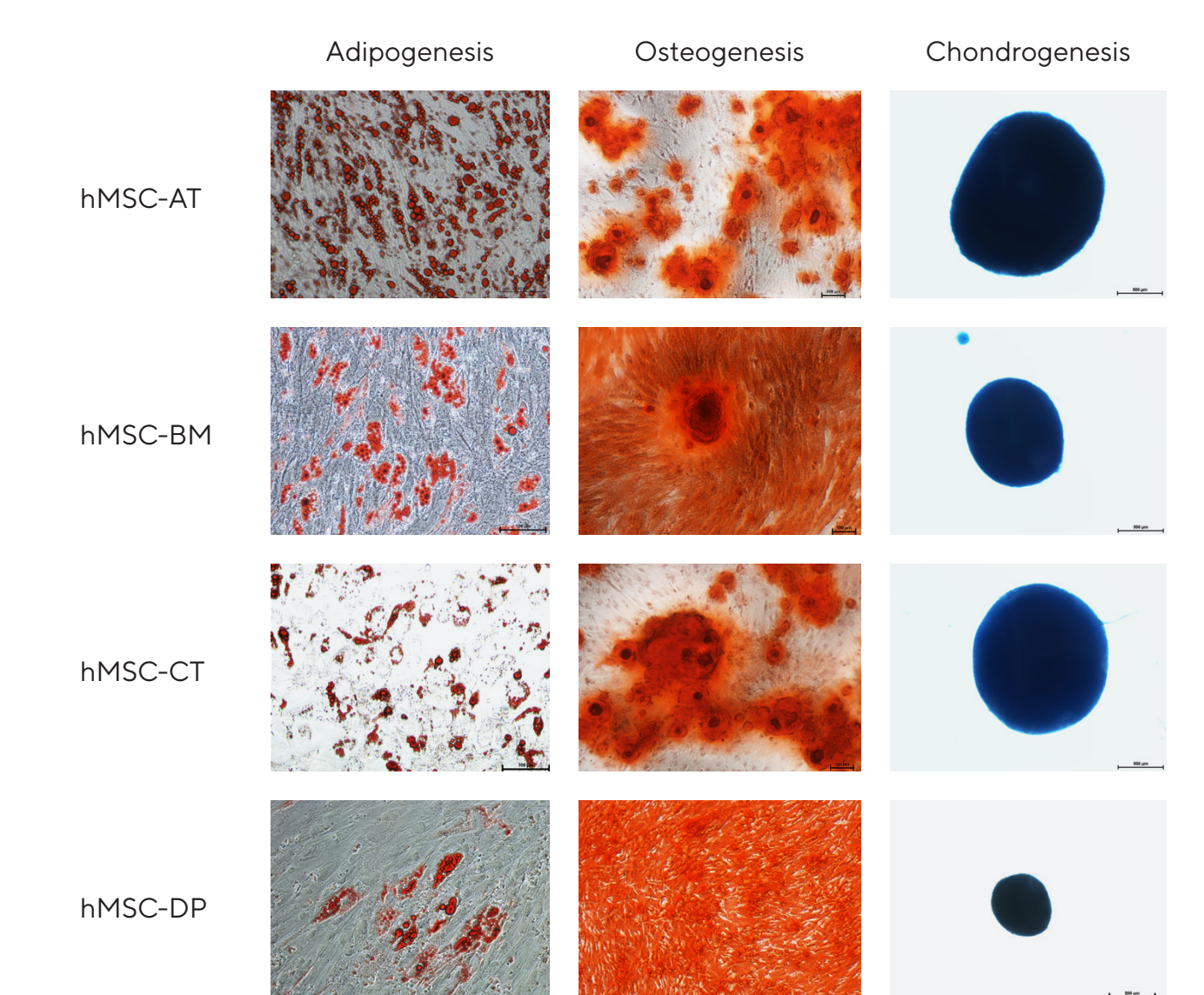
Each sample was tested in triplicates. The mRNA expression levels were normalized to the levels of undifferentiated hMSCs for matured genes, specific for each cell lineage.

Immunofluorescence (IF) staining: following differentiation, cells were fixed (4% formaldehyde) and immune stained as follow. The nuclei were counterstained with Dapi (Blue, MP Bioscience).

- Adipogenesis:** Fatty acid binding protein 4 (FABP4) was detected using Goat Anti-Mouse/Rat FABP4 polyclonal antibody (AF1443, R&D Systems) at $10 \mu\text{g}/\text{mL}$ for 24 hrs at $2 - 8^\circ\text{C}$, following staining with Rhodamine Red™-X conjugated donkey anti-goat IgG secondary antibody (red, Jackson).
- Osteogenesis:** OCN (BGLAP) was detected using Mouse Anti Human/Rat OCN monoclonal antibody (MAB1419, R&D Systems) at $10 \mu\text{g}/\text{mL}$ for 24 hrs at $2 - 8^\circ\text{C}$ following staining with Alexa Fluor™ 488-conjugated donkey anti-mouse IgG secondary antibody (green, Jackson).
- Chondrogenesis:** ACAN (Aggrecan) was detected using Goat Anti-Human Aggrecan Polyclonal Antibody (AF1220, R&D Systems) at $10 \mu\text{g}/\text{mL}$ for 24 hrs at $2 - 8^\circ\text{C}$, following staining with Rhodamine Red™-X donkey anti-goat IgG secondary antibody (red, Jackson).

Summary

Figure 12: Suitability for Various Sources of hMSCs



hMSCs from various sources differentiated into adipocytes (x200, Oil Red O), osteocytes (x100, ARS) and chondrocytes (x40, Alcian Blue) using BI MSCgo™ differentiation media (SF, XF). Adipogenesis: 16–24-day assay, osteogenesis: 11–15-day assay, chondrogenesis: 18–24-day assay.

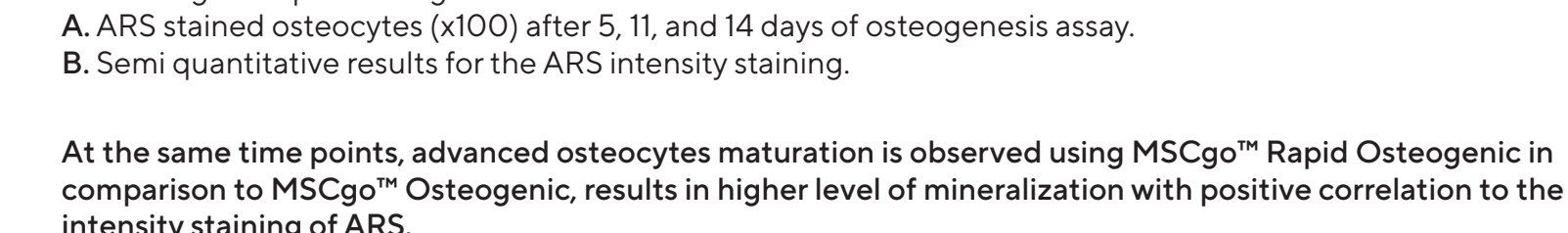
Efficient differentiation of hMSCs from various sources into adipocytes, osteocytes, and chondrocytes is achievable using a novel set of SF, XF differentiated media (BI).

- hMSCs from various sources can be efficiently differentiated into adipocytes, osteocytes, and chondrocytes under SF, XF culture conditions using the MSCgo™ differentiation media, respectively.
- Superior maturation of differentiated hMSCs can be achieved under SF, XF using the MSCgo™ differentiation media in comparison to competitor media.
- Rapid osteogenic maturation with intensive mineralization can be achieved using the MSCgo™ Rapid Osteogenic.

To conclude: The present study addressed the development of novel serum-free, xeno-free differentiation media that efficiently differentiate hMSCs from various sources into adipocytes, osteocytes, and chondrocytes.

This novel SF, XF system enables achieving defined conditions, for rapid generation of differentiated hMSCs towards tissue engineering and drug screening applications.

Figure 10: Mineralization Kinetics of hMSC-CT Differentiated In MSCgo™ Rapid Osteogenic



hMSC-CT seeded in SF, XF culture system (MSC NutriStem® XF and MSC Attachment Solution) for 24 hrs following initiation of osteogenesis using MSCgo™ Rapid Osteogenic. Representative images (x100) of osteogenic differentiated hMSC-CT after 5, 11 and 14 days in MSCgo™ Rapid Osteogenic.

Rapid mineralization is observed using MSCgo™ Rapid Osteogenic.

Figure 11: Rapid Osteogenesis Is Achievable Using MSCgo™ Rapid Osteogenic



hMSCs from various sources differentiated into adipocytes (x200, Oil Red O), osteocytes (x100, ARS) and chondrocytes (x40, Alcian Blue) using BI MSCgo™ differentiation media (SF, XF). Adipogenesis: 16–24-day assay, osteogenesis: 11–15-day assay, chondrogenesis: 18–24-day assay.

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