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Immunophenotypical characterization of canine mesenchymal stem cells from perivisceral and subcutaneous adipose tissue by a species-specific panel of antibodies

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Abstract: Immunophenotypical characterization of mesenchymal stem cells is fundamental for the design and execution of sound experimental and clinical studies. The scarce availability of species-specific antibodies for canine antigens has hampered the immunophenotypical characterization of canine mesenchymal stem cells (MSC). The aim of this study was to select a panel of species-specific direct antibodies readily useful for canine mesenchymal stem cells characterization. They were isolated from perivisceral and subcutaneous adipose tissue samples collected during regular surgeries from 8 dogs. Single color flow cytometric analysis of mesenchymal stem cells (P3) deriving from subcutaneous and perivisceral adipose tissue, with a panel of 7 direct anti-canine antibodies revealed two largely homogenous cell populations with a similar pattern: CD29+, CD44+, CD73+, CD90+, CD34-, CD45- and MHC-II- with no statistically significant differences among them. Antibody reactivity was demonstrated on canine peripheral blood mononuclear cells. The similarities are reinforced by their in vitro cell morphology, trilineage differentiation ability and RT-PCR analysis (CD90+, CD73+, CD105+, CD44+, CD13+, CD29+, Oct-4+ gene and CD31- and CD45- expression). Our results report for the first time a comparison between the immunophenotypic profile of canine MSC deriving from perivisceral and subcutaneous adipose tissue. The substantial equivalence between the two populations has practical implication on clinical applications, giving the opportunity to choose the source depending on the patient needs. The results contribute to routine characterization of MSC populations grown in vitro, a mandatory process for the definition of solid and reproducible laboratory and therapeutic procedures.

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1 Immunophenotypical characterization of canine mesenchymal  
2 stem cells from perivisceral and subcutaneous adipose tissue by  
3 a species-specific panel of antibodies

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22 **Abstract**

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28 mesenchymal stem cells (MSC). The aim of this study was to  
29 select a panel of species-specific direct antibodies readily  
30 useful for canine **mesenchymal stem cells MSC**  
31 characterization. ~~MSC~~ **They were** isolated from perivisceral  
32 (~~pAT-MSC~~) and subcutaneous (~~sAT-MSC~~) adipose tissue  
33 samples collected during regular surgeries from 8 dogs.. Single  
34 color flow cytometric analysis of **mesenchymal stem cells (P3)**  
35 **deriving from subcutaneous and perivisceral adipose tissue**  
36 ~~sAT-MSC and pAT-MSC (P3)~~ with a panel of 7 direct anti-  
37 canine antibodies revealed two largely homogenous cell  
38 populations with a similar pattern: CD29<sup>+</sup>, CD44<sup>+</sup>, CD73<sup>+</sup>,  
39 CD90<sup>+</sup>, CD34<sup>-</sup>, CD45<sup>-</sup> and MHC-II<sup>-</sup> with no statistically  
40 significant differences among them. **Antibody** ~~Antibodies~~  
41 reactivity was demonstrated on canine peripheral blood  
42 mononuclear cells. The similarities are reinforced by their *in*  
43 *vitro* cell morphology, trilineage differentiation ability and RT-  
44 PCR analysis (CD90<sup>+</sup>, CD73<sup>+</sup>, CD105<sup>+</sup>, CD44<sup>+</sup>, CD13<sup>+</sup>,  
45 CD29<sup>+</sup>, Oct-4<sup>+</sup> gene and CD31<sup>-</sup> and CD45<sup>-</sup> expression). Our  
46 results report for the first time a comparison between the

47 immunophenotypic profile of canine MSC deriving from  
48 perivisceral and subcutaneous adipose tissue ~~sAT-MSC~~ and  
49 ~~pAT-MSC~~. The substantial equivalence between the two  
50 populations has practical implication on clinical applications,  
51 giving the opportunity to choose the source depending on the  
52 patient needs. The results contribute to routine characterization  
53 of MSC populations grown *in vitro*, a mandatory process for  
54 the definition of solid and reproducible laboratory and  
55 therapeutic procedures.

56 **Key words: mesenchymal stem cells, dog, adipose tissue,**  
57 **species-specific antibody, immunophenotyping**

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68           **1. Introduction**

69   Regenerative medicine and tissue engineering are promising  
70   novel therapeutic approaches in veterinary medicine. In  
71   particular, mesenchymal stem cells (MSC) are ~~the most~~  
72   commonly used as a ~~option as a~~ therapeutic tool within the field  
73   of cell based therapies and have been the subject of a number of  
74   preclinical and clinical studies. Mesenchymal stem cells MSC  
75   are self-renewing, multipotent adult stem cells found near  
76   blood vessels in different organs such as bone marrow, adipose  
77   tissue, blood, umbilical cord, muscle, bone and cartilage. Due  
78   to their ability to differentiate into other cell types and to  
79   produce a wide range of immunomodulatory, trophic,  
80   angiogenic and anti-apoptotic bioactive molecules, MSC have a  
81   practical application in the field of cell therapy (Marx et al.,  
82   2015). The Mesenchymal and Tissue Stem Cell Committee of  
83   the International Society for Cellular Therapy defined them as a  
84   population of cells that satisfies the following criteria in vitro:  
85   1) adherence to a plastic surface and typical spindle-like shape;  
86   2) ability to differentiate in osteogenic, adipogenic and  
87   chondrogenic lineage and 3) the expression of a set of cell  
88   surface markers (Dominici et al., 2006).

89   ~~Cell surface marker characterization of human MSC by flow~~  
90   ~~cytometry has recently been carried out (Nery et al., 2013).~~

91 The expression of cell surface markers on MSC deriving from  
92 veterinary species is subject of intense research at the moment.

93 ~~On the contrary, there is little data regarding the expression of~~  
94 ~~cell surface markers on MSC derived from animal species.~~

95 ~~Detailed immunophenotyping analysis of equine MSC from~~  
96 ~~multiple sources was reported, including the expression of~~  
97 ~~CD29, CD44, CD73, CD90, CD105, CD14, CD34, CD45,~~  
98 ~~CD79a, and MHC II. Although a wide range of markers was~~  
99 ~~included in the study, the interpretation of the results was~~  
100 ~~strongly influenced by the use of anti human antibodies~~  
101 ~~(Paebst, et al., 2014). Several research groups have published~~  
102 ~~studies about the marker expression of canine MSC isolated~~  
103 ~~from subcutaneous or perivisceral adipose tissue, but the~~  
104 ~~current data are still incomplete. MSC from perivisceral~~  
105 ~~adipose tissue have been characterized as CD90, CD44,~~  
106 ~~CD140a and CD117 positive and CD34 and CD45 negative,~~  
107 ~~however there were no data about the origin of the antibodies~~  
108 ~~that were used (Martinello et al., 2011).~~

109 ~~Another flow cytometric analysis of canine MSC derived from~~  
110 ~~subcutaneous adipose tissue demonstrated a high expression of~~  
111 ~~CD29 and CD44, while CD90 was modestly expressed and~~  
112 ~~there was no expression of CD73, CD34 and CD45. In this~~  
113 ~~case, not all the antibodies used cross reacted with canine cells~~  
114 ~~and furthermore no control group was included for the~~  
115 ~~evaluation of antibody reactivity (Takemitsu et al., 2012).~~

116 ~~The immunophenotyping profile and gene expression of cell~~  
117 ~~surface markers was further studied on adipose derived MSC~~  
118 ~~that resulted positive for CD44, CD90 and MHC II; negative~~  
119 ~~for CD29, CD34 and MHC II using a panel of non-specific~~  
120 ~~canine antibodies (Screven et al., 2014) .~~

121 Recently, the dog gained interest as a preclinical/clinical model  
122 for cell-based therapies, and canine MSC have been isolated  
123 and studied *in vitro*. Furthermore, there is growing interest in  
124 the use of MSC in the treatment of injuries and diseases in  
125 dogs. Different sources and procedures for the preparation of  
126 canine MSC have been proposed and it is difficult to make a  
127 clear comparison between the various therapeutic approaches  
128 proposed and the clinical outcomes.

129 Therefore, in order to design and perform robust experimental  
130 and clinical studies in veterinary medicine, a fundamental step  
131 would be a sound characterization and description of the MSC.

132 The aim of our study was twofold, (1) to design a panel of  
133 canine species specific antibodies able to recognize the markers  
134 defining MSC (Dominici et al., 2006), readily useful for the  
135 immunophenotypic characterization of canine MSC. (2) To  
136 evaluate and compare the immunophenotypic profile of canine  
137 adipose-tissue derived MSC (AT-MSC) isolated from  
138 subcutaneous and perivisceral fat tissue, using the above  
139 defined panel of antibodies. Both information would be useful

140 for researchers involved in the set-up of cells-based  
141 regenerative therapies at both preclinical and experimental  
142 level in the dog.

## 143 **2. Materials and methods**

### 144 *2.1. Study design*

145 Eight client owned canine patients from different breeds, 5  
146 females and 3 males, weighing from 4 to 60 kg, aged between  
147 1,5 and 12 years were selected for adipose tissue sampling  
148 during scheduled surgical procedures (Table 1). Patients  
149 underwent routine clinical, biochemical and haematological  
150 examination prior the surgical procedure. All animal  
151 procedures and protocols were performed by licensed  
152 veterinary surgeons under standard ethical and sterile  
153 conditions. The owners signed an informed consent and agreed  
154 on the participation of their dogs.

155

### 156 *2.2. Sample collection*

157 Perivisceral and subcutaneous adipose tissue samples were  
158 collected during regular surgical procedures from 8 dogs with  
159 stable systemic conditions.

160 After collection each sample was transferred to a vial  
161 containing 20 ml of Dulbecco's Eagle Modified Medium  
162 (DMEM low glucose, Gibco) additioned with penicillin

163 (0.10U/ml), streptomycin (0,10 µg/ml) and amphotericin B (2,5  
164 µg/ml, Gibco) until cell isolation (not more than 4 hours).  
165 Peripheral blood samples for the isolation and flow cytometry  
166 analysis of peripheral blood mononuclear cells were collected  
167 from 3 healthy dogs prior to orthopaedic surgery. All the  
168 samples were collected following owner consent, under  
169 standard ethical and sterile conditions.

### 170 *2.3. Cell culture*

171 MSC from subcutaneous adipose tissue (sAT-MSC) and  
172 perivisceral adipose tissue (pAT-MSC) were isolated from  
173 adipose tissue samples weighing 2 grams. The samples were  
174 cut with scalpels in small pieces of 0,5 cm diameter and  
175 afterwards were transferred in a 15mL Conical Centrifuge  
176 *Falcon* Tube containing 10 ml of collagenase solution (DMEM  
177 low glucose, Gibco; penicillin 0,10 U/ml, Gibco; streptomycin  
178 0,10µg/ml, Gibco; amphotericin B 2,5 µg/ml, Gibco;  
179 collagenase type I 0,1% p/v). Enzymatic digestion was  
180 performed under a mechanical stirrer at 37°C for 45min.

181 The digested sample was then centrifuged (210xg for 8 min).  
182 After removal of the collagenase solution and the fat  
183 supernatant, the cell pellet was resuspended in 500µl  
184 maintenance medium (DMEM low glucose, Gibco added with  
185 10% fetal bovine serum (FBS), Gibco; penicillin 0,10U/ml,  
186 Gibco; streptomycin 0,10µg, Gibco; amfotericine B 2,5 µg/ml,

187 Gibco) and seeded in 25 cm<sup>2</sup> (Orange Scientific Tissue Culture  
188 Flasks) containing 5 ml of DMEM. The cells were maintained  
189 in an incubator at 37°C at 5% CO<sub>2</sub>. The medium was changed  
190 each 2-3 days. Cells were cultured to 80% confluence and then  
191 trypsinized with 0,05% Trypsin-EDTA solution (Gibco) The  
192 cell culture was grown until passage 3 (P3) when cells were  
193 used for the evaluation of the differentiation capacity, flow  
194 cytometric analysis and RT-PCR.

#### 195 *2.4.Tri-lineage cell differentiation*

##### 196 1. Adipogenic differentiation

197 MSC deriving from subcutaneous and perivisceral adipose  
198 tissue, at P3 were seeded in six-well plates at a density of 6 x  
199 10<sup>3</sup> cells/cm<sup>2</sup>. In each well, 3 ml of DMEM was added and the  
200 cells were incubated at 37°C and 5% CO<sub>2</sub>. At a confluency of  
201 80% they were treated with adipogenic differentiation media  
202 (StemPro Adipogenesis Differentiation Kit). The flasks were  
203 then put in an incubator with humidified atmosphere of 5%  
204 CO<sub>2</sub> and temperature of 37°C. Medium was changed each 2-3  
205 days. After 21 days the cells were fixed with 70% ethanol and  
206 stained with Oil Red O coloration.

##### 207 2. Chondrogenic differentiation

208 MSC deriving from subcutaneous and perivisceral adipose  
209 tissue, at passage 3 were seeded in six-well plates at a density

210 of  $6 \times 10^3$  cells/cm<sup>2</sup>. In each well 3 ml of DMEM was added  
211 and the cells were incubated at 37°C and 5% CO<sub>2</sub>. At a  
212 confluency of 80% they were treated with with chondrogenic  
213 differentiation medium (StemPro Chondrogenesis  
214 Differentiation Kit). The flasks were then put in an incubator  
215 with humidified atmosphere of 5% CO<sub>2</sub> and temperature of 37  
216 °C. Medium was changed each 2-3 days. After 21 days the cells  
217 were fixed with 4% formaldehyde and stained with Alcian blue.

### 218 3. Osteogenic differentiation

219 MSC deriving from subcutaneous and perivisceral adipose  
220 tissue, at passage 3 were seeded in six-well plates at a density  
221 of  $6 \times 10^3$  cells/cm<sup>2</sup>. In each well 3 ml of DMEM was added  
222 and the cells were incubated at 37°C and 5% CO<sub>2</sub>. Arriving at  
223 confluency of 80%, the cells were treated with osteogenic  
224 induction medium (DMEM additioned with 100nM  
225 dexamethasone, 10µM glycerophosphate and 0.250 mM  
226 ascorbic acid). Medium was changed each 2-3 days. After 21  
227 days the cells were fixed with 1% paraformaldehyde and  
228 stained with von Kossa staining (Bio Optica).

### 229 2.5. Immunophenotyping

230 Single color flow cytometry analysis was performed for the  
231 assessment of surface marker expression of cells from both  
232 sources of adipose tissue. The expression of the following

233 markers was evaluated: CD29, CD34, CD44, CD45, CD73,  
234 CD90 and MHC-II, using a panel of seven antibodies (Table 1).

235 At P3, MSC were trypsinized (0,05% Trypsin-EDTA, Gibco)  
236 and centrifuged at 210xg for 8 minutes. They were then  
237 resuspended in 3 ml of complete medium for cell count using a  
238 Burker's hemocytometer. Then,  $2.5 \times 10^4$  cells were transferred  
239 in conical and round bottom tubes for flow cytometry analysis,  
240 washed with 1 ml sterile PBS **supplemented with 1% fetal**  
241 **bovine serume (FBS)**, and then centrifuged at 210x g for 8  
242 minutes. The supernatant was eliminated and, in every tube, 5  
243  $\mu$ l of each antibody was added.

244 For every sample, one tube containing the same number of  
245 unmarked cells was evaluated as a negative control.

246 After dark incubation for 15 minutes at room temperature, 1ml  
247 of PBS was added and the cells were centrifuged at 210xg for 8  
248 minutes. The pellet was then added 0,5ml of PBS and evaluated  
249 by flow cytometry analysis (Cytomics FC 500, Beckman  
250 Coulter). Dead cells were excluded using SytoxAAdvanced  
251 Dead Cell Stain Kit (Life Technologies), according to the  
252 manufacturer's instructions.

253 Antibodies were tested on peripheral blood mononuclear cells  
254 (PBMC) of 3 healthy dogs to confirm reactivity. PBMC were  
255 isolated from 2 ml of 3 dog blood samples collected in lithium-  
256 heparin as anticoagulant by density gradient in Histopaque-

257 1077 solution (Sigma, St. Louis, MO) according to the  
258 manufacturer's instructions. Blood samples were taken and  
259 then stratified on Histopaque-1077 solution (1:1, v/v, Sigma)  
260 and centrifuged at  $400 \times g$  for 30 min; purified PBMC were  
261 washed with sterile Phosphate Buffer Solution (PBS) (Sigma)  
262 supplemented with 1% fetal FBS and resuspended in RPMI-  
263 1640 (Gibco, Carlsbad, CA, USA) supplemented with 10%  
264 FBS, 2 mM l-glutamine, 100mM non-essential amino-acids, 50  
265 mM 2-mercaptoethanol (Sigma) and 100 U/ml penicillin G,  
266 100  $\mu$ g/ml streptomycin and 0.25  $\mu$ g/ml amphotericin B.

267 Cells were counted by inverted optical microscope and  
268 concentration was assessed before being used for surface  
269 staining flow cytometry analysis. 400,000 cells were mixed  
270 with 5 $\mu$ l of the specific antibody for each surface antigen in a  
271 plastic tube, after an incubation for 15' in the dark at room  
272 temperature, cells were washed with PBS with 1% FBS,  
273 centrifuged for 5' at 400xg and re-suspended in 0.5 ml of  
274 PBS/1%FCS and finally set aside for flow cytometry analysis  
275 (Cytomics FC 500, Beckman Coulter).

## 276 *2.6.RT-PCR*

277 Assessment of the phenotypic expression of different cell  
278 markers was performed by Reverse-Transcriptase-PCR (RT-  
279 PCR). Total RNA was extracted from  $1.5 \times 10^6$  cells at P3 (80%  
280 of confluence) using the kit Nucleospin® RNA II (Macherey-

281 Nagel) following manufacturer's instructions. cDNA was then  
282 obtained via reverse transcription of 1.5µg of total RNA using  
283 RevertAit™ First Strand cDNA Synthesis Kit (Fermentas).  
284 PCR was performed using 2µl of cDNA. The final PCR  
285 mixture contained 1x amplification buffer with 2.5 mM MgCl<sub>2</sub>,  
286 10mM dNTP Mix (Thermo Scientific), 0,25µM specific  
287 forward and reverse primers, 1 U Dream Taq (Thermo  
288 Scientific) in a final volume of 25µl.

289 Table 2 reports the list of genes whose expression was  
290 analyzed, their gene accession number, the sequence of forward  
291 and reverse specific set of primers and the length of the relative  
292 amplicons. All PCRs were performed using the following  
293 protocol: denaturation at 94°C for 30 sec; annealing at 55°C for  
294 30 sec; extension at 72°C for 30 sec, with 35 cycles. The  
295 products of the RT-PCR were separated on agarose gel (1,5%  
296 P/V) in TAE buffer stained with 3,5µl ethidium bromide  
297 (10mg/ml). Amplicons were visualized under UV light with a  
298 trans-illuminator and images acquired by a Canon digital  
299 camera. The analysis was repeated with two different replicates  
300 for each tissue sample. A semi-quantitative analysis of the  
301 expression of MSCs markers was performed evaluating the  
302 optical density of each positive band by means of the ImageJ  
303 image processing software normalized to the expression of the  
304 housekeeping gene GAPDH.

305 *2.7. Statistical analysis*

306 The results of the immunophenotypic characterization of MSC  
307 deriving from perivisceral and subcutaneous adipose tissue  
308 were compared. Data was expressed as mean± standard  
309 deviation (SD). The differences among the groups were  
310 considered statistically significant for P<0.05 and Mood's  
311 median test was made as non-parametric statistics analysis. All  
312 the tests were made using SPSS 16 IBM software.

### 313 **3. Results**

#### 314 *3.1. Cell culture and isolation*

315 After 24 – 48 hours, cells were adherent to the surface of the  
316 flasks. Medium was changed after two-three days in order to  
317 eliminate non-adherent cells. During their growth, cells  
318 appeared as a homogeneous population of typical fibroblast-  
319 like cell morphology with elongated spindle like shape.

#### 320 *3.2. Tri-lineage cell differentiation*

321 Cell cultures at P3 ~~have~~ were able to differentiate into  
322 osteogenic, adipogenic and chondrogenic lineages. ~~A large~~  
323 ~~number of~~ **Cells stimulated with adipogenic medium** contained  
324 intracellular lipid vacuoles stained with Oil Red O, confirming  
325 the adipogenic differentiation of sAT-MSC and pAT-MSC,  
326 following the appropriate stimulation in vitro. Cells stimulated  
327 with osteogenic induction medium formed aggregates and had  
328 ~~numerous~~ extracellular calcium deposits, as by with von Kossa

329 staining confirmed the osteogenic differentiation of cells from  
330 both sources. The cell cultures treated with chondrogenic  
331 medium contained aggregates of proteoglycans stained in blue  
332 with Alcian Blue coloration. Control groups for each treatment  
333 showed no evidence of differentiation (Fig. 1).

### 334 *3.3.FACS analysis*

335 All antibodies tested on canine PBMC showed the expected  
336 reactivity (data not shown). For immunophenotypical analysis,  
337 the live population of MSC was gated in the scatter plot for  
338 further fluorescence intensity analysis in the histogram plot  
339 (Fig. 2).

340 Our data showed that MSC at P3 deriving from perivisceral and  
341 subcutaneous adipose tissue were positive for: CD29, CD44,  
342 CD73, CD90; and negative for CD34, CD45 and MHC-II  
343 (Tables 3, 4). There was no significant difference in surface  
344 antigen expression between the two groups of MSC.

### 345 *3.4.Reverse transcription analysis of gene expression*

346 Expression analysis of a panel of genes consisting of CD90,  
347 CD73, CD105, CD45, CD34, CD44, CD13, CD29, CD31 and  
348 Oct-4 was performed on sAT-MSC and pAT-MSC at P3. Both  
349 populations were negative for CD45 and CD31. pAT-MSC  
350 were also negative for CD34 expression, while sAT-MSC  
351 showed weak expression. All other genes of the panel were

352 expressed in both sAT-MSC and pAT-MSC. Semiquantitative  
353 analysis of marker profile, demonstrated a substantial  
354 equivalence between the two cell populations (Table 5).

#### 355 **4. Discussion**

356 MSC-based treatment has been increasingly applied in  
357 veterinary medicine in the recent years. Several studies have  
358 reported the beneficial effects for different pathological states  
359 in dogs (Black et al., 2008, Hall et al., 2010, Pogue et al., 2013,  
360 Alamoudi et al., 2014, Marx et al., 2014, Penha et al., 2014,  
361 Villatoro et al., 2015, Perez-Merino et al., 2015, Kim et al.,  
362 2015 and Lee et al., 2015). ~~horses (Del Bue et al., 2008, Rich~~  
363 ~~et al., 2014 and Govoni et al., 2015) and cats (Trzil, et al., 2015,~~  
364 ~~Quimby, et al., 2016).~~ Although the majority of the studies  
365 carried out contain a limited number of patients and often lack  
366 of appropriate controls, the results can be considered  
367 encouraging for the set-up of clinical protocols to be applied in  
368 veterinary medicine.

369 For the reliability of research studies dealing with biological  
370 properties of MSC and for the safety of clinical treatments  
371 based on these cells, it is necessary to have accurate cell  
372 characterization. The availability of several possible tissue  
373 sources, different methods of cell culture, expansion and  
374 handling, as well as a variety of possible therapeutic

375 approaches, represent a limit to the correct evaluation of the  
376 healing potential of these cells.

377 Following the basic criteria for the characterization of human  
378 MSC (Dominici et al., 2006), equivalent MSC derived from  
379 laboratory and domestic animals were demonstrated to have  
380 fibroblast-like shape, ability to differentiate into osteogenic,  
381 chondrogenic and adipogenic lineages and to have a  
382 determinate cell surface antigen pattern. ~~However, the lack of~~  
383 ~~species-specific antibodies has been a major drawback towards~~  
384 ~~the full and accurate immunophenotypic characterization of~~  
385 ~~animal-derived MSC.~~ Therefore, The first aim of our study was  
386 to select a panel of species-specific antibodies for the  
387 evaluation of cell surface CD ~~marker markers~~ expression in  
388 canine adipose tissue derived MSC that could be routinely used  
389 for the cell characterization prior to their use. **Having read**  
390 **previous studies addressing the same topic, we encountered a**  
391 **common statement declared by researchers, saying that their**  
392 **findings can be found unexpected or contradictory due to the**  
393 **low binding affinity of non species-specific antibodies used for**  
394 **the screening of cell surface markers (Screven et al., 2014).**  
395 **We hypothesized that by using a panel of species-specific**  
396 **antibodies this variable would be eliminated. The panel would**  
397 **give more reliable and reproducible results that are necessary**  
398 **for the correct characterization of MSC, since they have**

399 become an attractive cell therapy product for small as well as  
400 large animal veterinary practitioners.

401 A further aim was to compare the marker expression of MSC  
402 derived from subcutaneous and perivisceral adipose tissue.  
403 Indeed, the characterization of these two populations of MSC  
404 would be of practical relevance for their clinical use.

405 Subcutaneous adipose tissue is an easily available source of  
406 MSC. Samples of a few grams of fat tissue can be collected  
407 quickly and safely during surgery in dogs of different sizes,  
408 avoiding the potential risk associated with abdominal surgery  
409 or bone marrow aspiration. We hypothesized that by defining  
410 and comparing the cell surface pattern of subcutaneous and  
411 perivisceral adipose tissue, we could obtain data that will offer  
412 researchers and veterinary practitioners the opportunity to  
413 choose the source of MSC for their applications.

414

415 MSC derived from the two tissue sources were analysed at P3,  
416 as this passage is considered appropriate for obtaining an  
417 adequate number of cells, safe in terms of chromosome  
418 variability and genetic abnormalities, and, therefore, adequate  
419 for therapeutic applications (Binato et al., 2013). Cells-MSC  
420 from both tissue sources had a similar fibroblast-like  
421 morphology, were able to adhere to plastic surface, grew in  
422 monolayer and demonstrated the capacity to differentiate in

423 osteogenic, chondrogenic and adipogenic lineages when  
424 stimulated with appropriate induction medium. A previous  
425 study reported similar results (Guercio et al., 2013), but lacked  
426 the immunophenotypic characterization of the cell population.  
427 Thus, in the present study, we chose to determine the  
428 expression of a panel of cell surface CD markers (CD29, CD34,  
429 CD44, CD45, CD90, CD73 and MHC-II), typical for the MSC  
430 (Dominici et al., 2006) using **species-specific** anti-canine  
431 antibodies.

432 CD 105 - one of the three surface markers that define human  
433 MSC (Dominici et al., 2006), was not taken in consideration in  
434 our study since we were not able to find any commercially  
435 available anti canine - CD105 antigen. ~~canine antibodies.~~  
436 **However, by means of RT-PCR we analysed the CD105**  
437 **expression and it was found positive in both sAT-MSC and in**  
438 **pAT-MSC.**

439 Antibody reactivity was confirmed by flow cytometry of canine  
440 PBMC (Peripheral Blood Mononucleated Cells) that served as  
441 a positive control. Interestingly, canine AT-MSC derived from  
442 subcutaneous and perivisceral adipose tissue showed a similar  
443 immunophenotypic pattern, which from a practical point of  
444 view indicates that both tissues can be used as a valid source  
445 for the isolation of MSC. **Both cell populations can be defined**  
446 **as CD29<sup>+</sup>CD44<sup>+</sup>CD90<sup>+</sup>CD45<sup>-</sup>CD34<sup>-</sup>CD73<sup>-</sup>MHC-II<sup>-</sup>. As far as**  
447 **we know, this is the first study that characterized cAT-MSC by**

448 using a panel of canine species specific antibodies for both  
449 positive as well as negative markers. We are aware that culture  
450 conditions influence the immunophenotypic profile of MSC, as  
451 it has been demonstrated for example, by bFGF (Gharibi and  
452 Hughes, 2012). Therefore for each future characterization in  
453 different culture conditions it is recommended to take this fact  
454 in consideration. Different researchers included anti-human  
455 antibodies in their protocols, however, they cannot be  
456 considered fully reliable for the characterization of canine  
457 MSC. Rozemuller et al., 2010 studied the expression of surface  
458 cell surface marker expression on canine BM-MSC using a  
459 panel of 43 anti-human antibodies. 24 of them, among which  
460 CD73, CD90 and CD105 did react with human MSC, but failed  
461 to cross-react with canine MSC, therefore cannot be considered  
462 adequate for the definition of the immune phenotype of canine  
463 MSC.. Takemitsu et al., isolated and characterized canine AT-  
464 MSC obtaining surprisingly low results for the expression of  
465 CD90 and CD105, finding that can be justified by the fact that  
466 they used non canine specific antibodies. Similar findings were  
467 obtained by Screven et al. for CD105, as they stated that the  
468 low binding activity can be a consequence to the use of a  
469 nonspecific canine antibody.

470 By RT-PCR analysis, we analyzed the gene expression of the  
471 same markers analyzed with FACS analysis, including  
472 additionally Oct-4, CD105, CD13 and CD31. The positive

473 expression of Oct-4 demonstrated the pluripotency of both  
474 sAT-MSC as well as pAT-MSC, as it has already been  
475 described in canine (Neupane et al., 2008, Reich et al., 2012)  
476 and human (Han et al., 2014) AT-MSC. Furthermore, the cells  
477 resulted positive for CD13 and negative for CD 31. Although  
478 we did not evaluate CD105 expression by flow cytometry  
479 analysis, the RT-PCR revealed a positive expression for both  
480 sAT-MSC and pAT-MSC. As a whole the results obtained by  
481 flow cytometry were confirmed by RT-PCR, as the two cell  
482 populations demonstrated a similar qualitative pattern of  
483 expression, with the only exception of CD34. According to  
484 Takemitsu et al. (2012), and Screven et al. (2014), canine AT-MSC  
485 do not express CD34. However Russell et al. (2016) found a  
486 moderately high expression of CD34 on AT-MSC, explaining that  
487 actually the fat harvesting site does have an influence on surface  
488 markers expression. We indeed detected a positive, although low  
489 expression of CD34 at mRNA level in sAT-MSC. On the other hand  
490 at a protein level CD34 was absent. This finding could be explained  
491 with the observation that sometimes low level of gene transcription  
492 does not result in a significant protein synthesis (Screven et al.,  
493 2014).

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496 The comparison of the immunophenotypical profile of AT-  
497 MSC among canine, human and other species adipose tissue

498 derived MSC would be of interest, as the dog is considered a  
499 suitable animal model for the study of human diseases  
500 (Hoffman and Dow, 2016).

501 In comparison to laboratory animals, canine anatomy and  
502 physiology, as well as the prevalence in this species of natural  
503 occurring diseases with similar pathogenesis, more closely  
504 resemble humans. Dogs have a longer life-span, live in  
505 environments similar to humans and therefore are exposed to  
506 different external factors that are part of the aetiology of  
507 common diseases and conditions such as diabetes, obesity and  
508 tumors. Furthermore, the clinical follow-up is similar and there  
509 is a wide range of imaging techniques developed for veterinary  
510 patients (Volk and Theoret, 2013) suitable to provide solid  
511 knowledge about the clinical evolution of the diseases.

512 A complete overlap of marker expression between human MSC  
513 has yet to be demonstrated due to the lack of an extensive cell  
514 characterization in some species. However, similarities can be  
515 found between MSCs derived from domestic and laboratory  
516 animals and humans. Most of the markers analyzed in this  
517 study share a similar distribution in the different species, with  
518 the exception of CD73. We encountered a similar ~~identical~~  
519 expression of CD29, CD34, CD44, CD45, CD90 and MHC-II  
520 which could suggest that *in vitro* cultured canine MSC  
521 possibly share a similar immunophenotypic profile with human  
522 MSC (Takemitsu et al., 2012; Nery et al., 2012). The unique

523 difference found was in the expression of CD73, one of the  
524 three positive markers proposed for defining hMSC ( $\geq 95\%$ )  
525 (Dominici et al., 2006). Interestingly, we report here for the  
526 first time that the expression of CD73 is lower in **other animal**  
527 ~~an animal~~ species compared to humans (Table 6). This would  
528 suggest that there is a slightly different immunophenotypic  
529 profile that should be taken in consideration for the correct  
530 interpretation and characterization of AT-MSC in veterinary  
531 patients.

532 **Bone marrow has been commonly used in veterinary medicine**  
533 **as a source of MSC. Their immunophenotype has been**  
534 **described in different works. Malagola et al., (2016) by FACS**  
535 **analysis characterized cBM-MSC as**  
536 **CD105<sup>+</sup>CD90<sup>+</sup>CD166<sup>+</sup>CD29<sup>+</sup>CD45<sup>-</sup>. Additionally, Takemitsu**  
537 **et al. (2012) and Screven et al., (2014) compared the**  
538 **immunophenotypic profile of cAT-MSC and cBM-MSC, which**  
539 **resulted to be similar. However Screven et al., did not report**  
540 **any statistical analysis and compared cells collected at a**  
541 **different in vitro passage. Takemitsu et al., compared cells**  
542 **deriving from dogs having the same gender, similar age and**  
543 **weight, and bred in similar conditions. In the present work, on**  
544 **the other hand we have isolated cAT-MSC from canine patients**  
545 **having different age, gender, weight and living in different**  
546 **environments. Therefore, we compared our results with the**

547 immunophenotypical characteristics previously described for  
548 bone marrow derived MSC Takemitsu et al., 2012. (Table 7).  
549 Both profiles are similar in terms of CD29 and CD44 as  
550 positive markers and CD34, CD45 and MHC-II as negative  
551 markers. A difference exists in the expression of CD73 and  
552 CD90, which appears to be lower in BM-MSc. However, the  
553 authors used noncanine-specific antibodies for the analysis,  
554 which can have an influence on the interpretation of the  
555 percentage of expression. Altogether, the results presented in  
556 Table 7 indicate a quite similar profile between canine adipose  
557 tissue and bone marrow derived MSC.

## 558 **5. Conclusions**

559 In the present paper we suggest a panel of antibodies  
560 specific to canine antigens suitable for the characterization  
561 of canine MSC by cytofluorimetry, i.e. CD29, CD34, CD44,  
562 CD45, CD90, CD73 and MHC-II. Using this panel of  
563 antibodies, we demonstrated that MSC derived from  
564 subcutaneous and perivisceral fat tissue samples shares an  
565 overlapping immune-profile, suggesting that the choice of  
566 the source of adipose tissue collected to expand MSC to be  
567 used in clinical practice, could be decided by the  
568 veterinarian on the basis of clinical considerations and not  
569 as a consequence of biological difference between cells  
570 derived from the two different sources. Furthermore, the

571 immunophenotype described by our panel of antibodies  
572 also suggests that adipose tissue derived MSC and bone  
573 marrow derived MSC show a similar profile. However, we  
574 would like to point out that additional studies are necessary  
575 to broaden the above listed panel of antibodies, in order to  
576 obtain a more accurate characterization of the  
577 immunophenotype of MSC.

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#### 579 **Conflict of interest statement**

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585 Cabibbo for the help in collecting adipose tissue samples.

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595 **Table 1. Canine patients' donors of adipose tissue samples**

<b>Patient</b>	<b>Gender</b>	<b>Age</b>	<b>Breed</b>	<b>Weight</b>	<b>Sampling collection location</b>
<b>Dog 1</b>	Female	1.5 years	Mixed-breed	10kg	Tela subserosa of the perimetrium
<b>Dog 2</b>	Female	9 years	German shepherd	35kg	Abdominal subcutaneous adipose tissue
<b>Dog 3</b>	Female	8 years	Newfoundland	60kg	Mesenteric adipose tissue
<b>Dog 4</b>	Female	12 years	Mixed-breed	30kg	Abdominal subcutaneous adipose tissue
<b>Dog 5</b>	Female	6 years	Mixed-breed	23kg	Tela subserosa of the perimetrium
<b>Dog 6</b>	Male	2 years	Mixed-breed	4kg	Falciform ligament
<b>Dog 7</b>	Female	11 years	Mixed-breed	8kg	Abdominal subcutaneous adipose tissue
<b>Dog 8</b>	Male	4 years	German shepherd	40kg	Abdominal subcutaneous adipose tissue

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608 **Table 2. Description of the panel of antibodies**

<b>Target cell marker</b>	<b>Clone</b>	<b>Isotype</b>	<b>Antibody Label</b>	<b>Reactivity</b>	<b>Production company</b>
<b>CD 29</b>	TS2/16	IgG1,k	PE	Human;Dog; Bovine	BioLegend
<b>CD 34</b>	1H6	IgG1	PE	Dog	eBioscience
<b>CD 44</b>	YKIX337. 8	IgG2a,k	FITC	Dog	eBioscience
<b>CD 45</b>	YKIX716. 13	IgG2b,k	FITC	Dog	eBioscience
<b>CD 73</b>	Polyclonal	IgG	Alexa Fluor 647	Human;Mouse;Rat; Dog; Chicken	Bioss
<b>CD 90</b>	YKIX337. 217	IgG2b,k	PE	Dog	eBioscience
<b>MHC-II</b>	YKIX337. 8	IgG2a,k	APC	Dog	eBioscience

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627 **Table 3. Markers used for the evaluation of cell surface**  
 628 **markers expression of MSC by RT-PCR**

Markers	Accession Number	Primers	Amplicon size
<b>CD 13</b>	NM_00114 6034.1	Fw: GGTCCTTACCATCACCTG GC Rv: CCTAAGGCCATCCATCGT CC	335bp
<b>CD 29</b>	XM_00561 6949.1	Fw: AGGATGTTGACGACTGCT GG Rv: ACCTTTGCATTCAGTGTT GTGC	356bp
<b>CD 31</b>	XM_84832 6	Fw: GCCCGAAGTTCACTCTCA AG Rv:CACTCCTTTGACCCAC ACCT	410bp
<b>CD 34</b>	NM_00100 3341.1	Fw: GAGATCACCTAACGCCT GG Rv: GGCTCCTTCTCACACAGG AC	383bp
<b>CD 44</b>	NM_00119 7022.1	Fw: CCCATTACCAAAGACCAC GA Rv: TTCTCGAGGTTCCGTGTC TC	408bp
<b>CD 45</b>	XM_00562 2282.1	Fw: TGTTTCCAGTTCTGTTTCC CCA Rv: TCAGGTACAAAGCCTTCC CA	432bp
<b>CD 73</b>	XM_53222 1.4	Fw: GATGGGAAAGGCAAGAG GCT Rv: TTCCTGGCATCTTGCTAC GG	317bp
<b>CD 90</b>	NM_00128 7129.1	Fw: AAGCCAGGATTGGGGAT GTG Rv: TGTGGCAGAGAAAGCTCC TG	285bp
<b>CD 105</b>	XM_00562 5330.2	Fw: GCTGAGGACAGAGATGA	421bp

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<b>Oct-4</b>	XM_53883	CCA	
	0.1	Rv:	
		CACGGAGGAGGAAGCTG	
		AAG	
		Fw:	286bp
		AAGCCTGCAGAAAGACCT	
		G	
		Rv:	
		GTTTCGCTTTCTCTTTTCGGG	
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651 **Table 4. Flow cytometric analysis of adipose tissue derived**  
 652 **MSC**

<b>Markers</b>	<b>sAT-MSC<sup>a</sup></b>	<b>pAT-MSC<sup>b</sup></b>
<b>CD 29</b>	99.5%±0.6	99.2%±1.5
<b>CD 34</b>	0.5%±1	0.25%±0.5
<b>CD 44</b>	78%±17	76.7%±18
<b>CD 45</b>	0.25%±0.5	0.5%±0.6
<b>CD 73</b>	14%±12.3	17%±14
<b>CD 90</b>	89%±6.7	79.5%±7.1
<b>MHC-II</b>	4.5%±6.3	4.5%±6.4

653 a and b: Data are displayed as percentages expressed as mean ± SD. Mood's median

654 test was applied and no statistical difference for P<0.05 was found.

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674 **Table 5. Summary of cell surface markers expression**  
 675 **measured by flow cytometry analysis**

Cells	CD29	CD34	CD44	CD45	CD73	CD90	MHC-II
sAT- MSC	+++ <sup>b</sup>	- <sup>c</sup>	+++ <sup>b</sup>	- <sup>c</sup>	++ <sup>a</sup>	+++ <sup>b</sup>	- <sup>c</sup>
pAT- MSC	+++ <sup>b</sup>	- <sup>c</sup>	+++ <sup>b</sup>	- <sup>c</sup>	++ <sup>a</sup>	+++ <sup>b</sup>	- <sup>c</sup>
<b>PBMC</b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>	<b>+++<sup>b</sup></b>

676 **a** ++ (10-40% positive cells)

677 **b** +++ (>40% positive cells)

678 **c** - (<5% positive cells).

679 Different groups are classified as described by Screven et al 2014

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695 **Table 6. Gene expression analysis of pAT-MSC and sAT-**  
 696 **MSC using semi-quantitative RT-PCR**

Cell marker	pAT-MSC	sAT-MSC
CD90	+++ <sup>d</sup>	+++ <sup>d</sup>
CD73	++ <sup>c</sup>	++ <sup>c</sup>
CD105	++ <sup>c</sup>	++ <sup>c</sup>
CD45	- <sup>a</sup>	- <sup>a</sup>
CD34	- <sup>a</sup>	+ <sup>b</sup>
CD44	+++ <sup>d</sup>	+++ <sup>d</sup>
CD13	+++ <sup>d</sup>	+++ <sup>d</sup>
CD29	+++ <sup>d</sup>	+++ <sup>d</sup>
CD31	- <sup>a</sup>	- <sup>a</sup>
Oct-4	+ <sup>b</sup>	+ <sup>b</sup>

- 697 **a** – (not expressed)
- 698 **b** + (<25% of GAPDH signal)
- 699 **c** ++ (25-50% of GAPDH signal)
- 700 **d** +++ (>50% of GAPDH signal)
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720 **Table 7. Comparison of the immunophenotypic profile of**  
 721 **adipose derived MSC from multiple species**

Species	Marker expression						
	CD 29	CD 34	CD 44	CD 45	CD 73	CD 90	MHC-II
<b>Human<sup>e</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Mouse<sup>f</sup></b>	+++ <sup>c</sup>	/ <sup>d</sup>	+++ <sup>c</sup>	- <sup>a</sup>	++ <sup>b</sup>	+++ <sup>c</sup>	/ <sup>d</sup>
<b>Rat<sup>g</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	/ <sup>d</sup>	- <sup>a</sup>	/ <sup>d</sup>	/ <sup>d</sup>	/ <sup>d</sup>
<b>Dog<sup>h</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	++ <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Horse<sup>i</sup></b>	/ <sup>d</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Cat<sup>j</sup></b>	/ <sup>d</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	/ <sup>d</sup>	+++ <sup>c</sup>	/ <sup>d</sup>

722 **a** - (<5% positive cells)

723 **b** ++ (10-40% positive cells)

724 **c** +++ (>40% positive cells)

725 **d** / (not known)

726 Different groups are classified as described by Screven et al 2014

727 **e** (Dominici et al., 2006)

728 **f** (Taha and Hedayati, 2010) (Laschke et al., 2013)

729 **g** (Lotfy et al., 2014) (Tapp et al., 2008)

730 **h** *our results*

731 **i** (de Mattos Carvalho et al., 2009)(Pascucci et al., 2011)(Barberini et al., 2014)

732 **j** (Kono et al., 2014)

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747 **Table 8. Comparison of the expression of the**  
 748 **immunophenotypic profile between MSC deriving from**  
 749 **subcutaneous adipose tissue, perivisceral adipose tissue and**  
 750 **bone marrow**

Markers	sAT-MSC	pAT-MSC	BM-MSC <sup>a</sup>
<b>CD 29</b>	99.5%±0.6	99.2%±1.5	98.41±0.53
<b>CD34</b>	0.5%±1	0.25%±0.5	0.88±0.21
<b>CD 44</b>	78%±17	76.7%±18	98.90±0.25
<b>CD 45</b>	0.25%±0.5	0.5%±0.6	0.24±0.07
<b>CD 73</b>	14%±12.3	17%±14	0.0081±0.01
<b>CD 90</b>	89%±6.7	79.5%±7.1	19.10±2.10
<b>MHC-II</b>	4.5%±6.3	4.5%±6.4	2.85±1.35

751 <sup>a</sup>Takemitsu et al., 2012

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767 **Figure 1** In vitro tri-lineage cell differentiation

768 Photomicrographs of canine perivisceral adipose tissue derived  
769 MSC- (pAT-MSC: **b, f, j**) and canine subcutaneous adipose  
770 tissue derived MSC (sAT-MSC: **d, g, l**), after 21 days of  
771 culture in adipogenic (**b, d**), chondrogenic (**f, h**), osteogenic  
772 (**j,l**) induction medium. Parallely a control culture of pAT-MSC  
773 (**a, e, i**) and sAT-MSC (**c, g, k**) was grown for 21 days in  
774 DMEM. Adipogenic differentiation is evidenced with the  
775 presence of intracellular vacuoles colored in red (black arrow)  
776 with Oil Red O staining, in pAT-MSC (**b**) and sAT- MSC (**d**),  
777 which are absent in control groups (**a,c**) (40X, scale bar  
778 200µm). Alcian blue staining indicated the presence of  
779 aggregates of proteglycans present in treated pAT-MSC (**f**) and  
780 sAT-MSC (**h**), and their absence in the control cultures (**e,h**)  
781 (10X, scale bar 100µm). Osteogenic differentiation was  
782 indicated with extracellular calcium aggregates stained with  
783 von Kossa coloration in pAT-MSC (**j**) and sAT-MSC (**l**)  
784 stimulated with ostegenic medium. Control groups did not  
785 contain any calcium aggregates (**i, k**) (10X, scale bar 100um).

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789 **Figure 2** Flow cytometry analysis of the expression of cell  
790 surface markers on sAT-MSC and pAT-MSC

791 The expression of cell surface markers is presented in two  
792 panels. The upper panel (a) contains data regarding the MSC  
793 deriving from subcutaneous adipose tissue and the low panel  
794 (b) data about MSC deriving from perivisceral adipose tissue.  
795 Live cell populations were gated in forward and side scatter for  
796 further analysis. Each histogram contains two peaks. The  
797 shaded red peak represents the actual expression of the markers  
798 for each cell group, on the other hand the transparent one is the  
799 negative control.

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- 1 Highlights
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- 3 • The design of MSC based therapeutic protocols requires an
- 4 accurate cell characterization
- 5 • Selection of a panel of 7 species specific anti-
- 6 canine antibodies for flow cytometric
- 7 characterization of canine AT-MSC
- 8 • Canine AT-MSC from subcutaneous and perivisceral
- 9 adipose tissue have a similar
- 10 immunophenotypic profile
- 11 • Comparison of the immunophenotypical profile of
- 12 AT-MSC from veterinary species,
- 13 laboratory animals and human origin
- 14 • AT-MSC derived from animal species have a lower CD73
- 15 expression compared to human
- 16 AT-MSC

1 Immunophenotypical characterization of canine mesenchymal  
2 stem cells from perivisceral and subcutaneous adipose tissue by  
3 a species-specific panel of antibodies

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22 **Abstract**

23 Immunophenotypical characterization of mesenchymal stem  
24 cells (MSC) is fundamental for the design and execution of  
25 sound experimental and clinical studies. The scarce availability  
26 of species-specific antibodies for canine antigens has hampered  
27 the immunophenotypical characterization of canine MSC. The  
28 aim of this study was to select a panel of species-specific direct  
29 antibodies readily useful for canine MSC characterization.  
30 MSC isolated from perivisceral (pAT-MSC) and subcutaneous  
31 (sAT-MSC) adipose tissue samples collected during regular  
32 surgeries from 8 dogs, were cultured *in vitro* under standard  
33 conditions. Single color flow cytometric analysis of sAT-MSC  
34 and pAT-MSC (P3) with a panel of 7 direct anti-canine  
35 antibodies revealed two largely homogenous cell populations  
36 with a similar pattern: CD29<sup>+</sup>, CD44<sup>+</sup>, CD73<sup>+</sup>, CD90<sup>+</sup>, CD34<sup>-</sup>,  
37 CD45<sup>-</sup> and MHC-II<sup>-</sup> with no statistically significant differences  
38 among them. Antibodies reactivity was demonstrated on canine  
39 peripheral blood mononuclear cells. The similarities are  
40 reinforced by their *in vitro* cell morphology, trilineage  
41 differentiation ability and RT-PCR analysis (CD90<sup>+</sup>, CD73<sup>+</sup>,  
42 CD105<sup>+</sup>, CD44<sup>+</sup>, CD13<sup>+</sup>, CD29<sup>+</sup>, Oct-4<sup>+</sup> gene and CD31<sup>-</sup> and  
43 CD45<sup>-</sup> expression). Our results report for the first time a  
44 comparison between the immunophenotypic profile of canine  
45 sAT-MSC and pAT-MSC. The substantial equivalence between  
46 the two populations has practical implication on clinical

47 applications, giving the opportunity to choose the source  
48 depending on the patient needs. The results contribute to  
49 routine characterization of MSC populations grown *in vitro*, a  
50 mandatory process for the definition of solid and reproducible  
51 laboratory and therapeutic procedures.

52 **Key words: mesenchymal stem cells, dog, adipose tissue,**  
53 **species-specific antibody, immunophenotyping**

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67           **1. Introduction**

68   Regenerative medicine and tissue engineering are promising  
69   novel therapeutic approaches in veterinary medicine. In  
70   particular, mesenchymal stem cells (MSC) are the most  
71   common option as a therapeutic tool and have been the subject  
72   of a number of preclinical and clinical studies. MSC are self-  
73   renewing, multipotent adult stem cells found near blood vessels  
74   in different organs such as bone marrow, adipose tissue, blood,  
75   umbilical cord, muscle, bone and cartilage. Due to their ability  
76   to differentiate into other cell types and to produce a wide  
77   range of immunomodulatory, trophic, angiogenic and anti-  
78   apoptotic bioactive molecules, MSC have a practical  
79   application in the field of cell therapy (Marx et al., 2015).

80   The Mesenchymal and Tissue Stem Cell Committee of the  
81   International Society for Cellular Therapy defined them as a  
82   population of cells that satisfies the following criteria in vitro:  
83   1) adherence to a plastic surface and typical spindle-like shape;  
84   2) ability to differentiate in osteogenic, adipogenic and  
85   chondrogenic lineage and 3) the expression of a set of cell  
86   surface markers (Dominici et al., 2006).

87   Cell surface marker characterization of human MSC by flow  
88   cytometry has recently been carried out (Nery et al., 2013).

89   On the contrary, there is little data regarding the expression of  
90   cell surface markers on MSC derived from animal species.

91 Detailed immunophenotyping analysis of equine MSC from  
92 multiple sources was reported, including the expression of  
93 CD29, CD44, CD73, CD90, CD105, CD14, CD34, CD45,  
94 CD79a, and MHC-II. Although a wide range of markers was  
95 included in the study, the interpretation of the results was  
96 strongly influenced by the use of anti-human antibodies  
97 (Paebst, et al., 2014). Several research groups have published  
98 studies about the marker expression of canine MSC isolated  
99 from subcutaneous or perivisceral adipose tissue, but the  
100 current data are still incomplete. MSC from perivisceral  
101 adipose tissue have been characterized as CD90, CD44,  
102 CD140a and CD117 positive and CD34 and CD45 negative,  
103 however there were no data about the origin of the antibodies  
104 that were used (Martinello et al., 2011).

105 Another flow cytometric analysis of canine MSC derived from  
106 subcutaneous adipose tissue demonstrated a high expression of  
107 CD29 and CD44, while CD90 was modestly expressed and  
108 there was no expression of CD73, CD34 and CD45. In this  
109 case, not all the antibodies used cross-reacted with canine cells  
110 and furthermore no control group was included for the  
111 evaluation of antibody reactivity (Takemitsu et al., 2012).

112 The immunophenotyping profile and gene expression of cell  
113 surface markers was further studied on adipose derived MSC  
114 that resulted positive for CD44, CD90 and MHC-II; negative

115 for CD29, CD34 and MHC-II using a panel of non-specific  
116 canine antibodies (Screven et al., 2014) .

117 There is growing interest in the use of MSC in the treatment of  
118 injuries and diseases in dogs. Different sources and procedures  
119 for the preparation of canine MSC have been proposed and it is  
120 difficult to make a clear comparison between the various  
121 therapeutic approaches proposed and the clinical outcomes.

122 Therefore, in order to design and perform robust experimental  
123 and clinical studies in veterinary medicine, a fundamental step  
124 would be a sound characterization and description of the MSC.

125 The aim of the present work was to select a panel of species-  
126 specific direct antibodies that can be readily used for the  
127 characterization of canine MSC. In particular, taking in  
128 consideration the relatively easy and low invasive procedures  
129 needed to collect tissue samples, we chose to perform the  
130 immunophenotype characterization of adipose tissue derived  
131 MSC. Using a defined panel of antibodies, we compared MSC  
132 deriving from two different adipose tissue sources, i.e.  
133 subcutaneous and perivisceral adipose tissue.

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138        **2. Materials and methods**

139        *2.1. Sample collection*

140        Perivisceral and subcutaneous adipose tissue samples were  
141        collected during regular surgical procedures from 8 dogs with  
142        stable systemic conditions.

143        After collection each sample was transferred to a vial  
144        containing 20 ml of Dulbecco's Eagle Modified Medium  
145        (DMEM low glucose, Gibco) additioned with penicillin  
146        (0,10U/ml), streptomycin (0,10 µg/ml) and amphotericin B (2,5  
147        µg/ml, Gibco) until cell isolation (not more than 4 hours).

148        Peripheral blood samples for the isolation and flow cytometry  
149        analysis of peripheral blood mononuclear cells were collected  
150        from 3 healthy dogs prior to orthopaedic surgery. All the  
151        samples were collected following owner consent, under  
152        standard ethical and sterile conditions.

153        *2.2. Cell culture*

154        MSC from subcutaneous adipose tissue (sAT-MSC) and  
155        perivisceral adipose tissue (pAT-MSC) were isolated from  
156        adipose tissue samples weighing 2 grams. The samples were  
157        cut with scalpels in small pieces of 0,5 cm diameter and  
158        afterwards were transferred in a 15mL Conical Centrifuge  
159        *Falcon* Tube containing 10 ml of collagenase solution (DMEM  
160        low glucose, Gibco; penicillin 0,10 U/ml, Gibco; streptomycin

161 0,10µg/ml, Gibco; amphotericin B 2,5 µg/ml, Gibco;  
162 collagenase type I 0,1% p/v). Enzymatic digestion was  
163 performed under a mechanical stirrer at 37°C for 45min.

164 The digested sample was then centrifuged (210xg for 8 min).  
165 After removal of the collagenase solution and the fat  
166 supernatant, the cell pellet was resuspended in 500µl  
167 maintenance medium (DMEM low glucose, Gibco added with  
168 10% fetal bovine serum (FBS), Gibco; penicillin 0,10U/ml,  
169 Gibco; streptomycin 0,10µg, Gibco; amfotericine B 2,5 µg/ml,  
170 Gibco) and seeded in 25 cm<sup>2</sup> (Orange Scientific Tissue Culture  
171 Flasks) containing 5 ml of DMEM. The cells were maintained  
172 in an incubator at 37°C at 5% CO<sub>2</sub>. The medium was changed  
173 each 2-3 days. Cells were cultured to 80% confluence and then  
174 trypsinized with 0,05% Trypsin-EDTA solution (Gibco) The  
175 cell culture was grown until passage 3 (P3) when cells were  
176 used for the evaluation of the differentiation capacity, flow  
177 cytometric analysis and RT-PCR.

### 178 *2.3.Tri-lineage cell differentiation*

#### 179 1. Adipogenic differentiation

180 MSC deriving from subcutaneous and perivisceral adipose  
181 tissue, at P3 were seeded in six-well plates at a density of 6 x  
182 10<sup>3</sup> cells/cm<sup>2</sup>. In each well, 3 ml of DMEM was added and the  
183 cells were incubated at 37°C and 5% CO<sub>2</sub>. At a confluency of  
184 80% they were treated with adipogenic differentiation media

185 (StemPro Adipogenesis Differentiation Kit). The flasks were  
186 then put in an incubator with humidified atmosphere of 5%  
187 CO<sub>2</sub> and temperature of 37°C. Medium was changed each 2-3  
188 days. After 21 days the cells were fixed with 70% ethanol and  
189 stained with Oil Red O coloration.

## 190 2. Chondrogenic differentiation

191 MSC deriving from subcutaneous and perivisceral adipose  
192 tissue, at passage 3 were seeded in six-well plates at a density  
193 of  $6 \times 10^3$  cells/cm<sup>2</sup>. In each well 3 ml of DMEM was added  
194 and the cells were incubated at 37°C and 5% CO<sub>2</sub>. At a  
195 confluency of 80% they were treated with with chondrogenic  
196 differentiation medium (StemPro Chondrogenesis  
197 Differentiation Kit). The flasks were then put in an incubator  
198 with humidified atmosphere of 5% CO<sub>2</sub> and temperature of 37  
199 °C. Medium was changed each 2-3 days. After 21 days the cells  
200 were fixed with 4% formaldehyde and stained with Alcian blue.

## 201 3. Osteogenic differentiation

202 MSC deriving from subcutaneous and perivisceral adipose  
203 tissue, at passage 3 were seeded in six-well plates at a density  
204 of  $6 \times 10^3$  cells/cm<sup>2</sup>. In each well 3 ml of DMEM was added  
205 and the cells were incubated at 37°C and 5% CO<sub>2</sub>. Arriving at  
206 confluency of 80%, the cells were treated with osteogenic  
207 induction medium (DMEM additioned with 100nM  
208 dexamethasone, 10µM glycerophosphate and 0.250 mM

209 ascorbic acid). Medium was changed each 2-3 days. After 21  
210 days the cells were fixed with 1% paraformaldehyde and  
211 stained with von Kossa staining (Bio Optica).

#### 212 *2.4.Immunophenotyping*

213 Single color flow cytometry analysis was performed for the  
214 assessment of surface marker expression of cells from both  
215 sources of adipose tissue. The expression of the following  
216 markers was evaluated: CD29, CD34, CD44, CD45, CD73,  
217 CD90 and MHC-II, using a panel of seven antibodies (Table 1).

218 At P3, MSC were trypsinized (0,05% Trypsin-EDTA, Gibco)  
219 and centrifuged at 210xg for 8 minutes. They were then  
220 resuspended in 3 ml of complete medium for cell count using a  
221 Burker's hemocytometer. Then,  $2.5 \times 10^4$  cells were transferred  
222 in conical and round bottom tubes for flow cytometry analysis,  
223 washed with 1 ml sterile PBS and then centrifuged at 210x g  
224 for 8 minutes. The supernatant was eliminated and, in every  
225 tube, 5  $\mu$ l of each antibody was added.

226 For every sample, one tube containing the same number of  
227 unmarked cells was evaluated as a negative control.

228 After dark incubation for 15 minutes at room temperature, 1ml  
229 of PBS was added and the cells were centrifuged at 210xg for 8  
230 minutes. The pellet was then added 0,5ml of PBS and evaluated  
231 by flow cytometry analysis (Cytomics FC 500, Beckman

232 Coulter). Dead cells were excluded using SytoxAAAdvanced  
233 Dead Cell Stain Kit (Life Technologies), according to the  
234 manufacturer's instructions.

235 Antibodies were tested on peripheral blood mononuclear cells  
236 (PBMC) of 3 healthy dogs to confirm reactivity. PBMC were  
237 isolated from 2 ml of 3 dog blood samples collected in lithium-  
238 heparin as anticoagulant by density gradient in Histopaque-  
239 1077 solution (Sigma, St. Louis, MO) according to the  
240 manufacturer's instructions. Blood samples were taken and  
241 then stratified on Histopaque-1077 solution (1:1, v/v, Sigma)  
242 and centrifuged at  $400 \times g$  for 30 min; purified PBMC were  
243 washed with sterile Phosphate Buffer Solution (PBS) (Sigma)  
244 supplemented with 1% fetal bovine serum (FBS) and  
245 resuspended in RPMI-1640 (Gibco, Carlsbad, CA, USA)  
246 supplemented with 10% FBS, 2 mM l-glutamine, 100mM non-  
247 essential amino-acids, 50 mM 2-mercaptoethanol (Sigma) and  
248 100 U/ml penicillin G, 100  $\mu$ g/ml streptomycin and 0.25  $\mu$ g/ml  
249 amphotericin B.

250 Cells were counted by inverted optical microscope and  
251 concentration was assessed before being used for surface  
252 staining flow cytometry analysis. 400,000 cells were mixed  
253 with 5 $\mu$ l of the specific antibody for each surface antigen in a  
254 plastic tube, after an incubation for 15' in the dark at room  
255 temperature, cells were washed with PBS with 1% FBS,

256 centrifuged for 5' at 400xg and re-suspended in 0.5 ml of  
257 PBS/1%FCS and finally set aside for flow cytometry analysis  
258 (Cytomics FC 500, Beckman Coulter).

### 259 *2.5.RT-PCR*

260 Assessment of the phenotypic expression of different cell  
261 markers was performed by Reverse-Transcriptase-PCR (RT-  
262 PCR). Total RNA was extracted from  $1.5 \times 10^6$  cells at P3 (80%  
263 of confluence) using the kit Nucleospin® RNA II (Macherey-  
264 Nagel) following manufacturer's instructions. cDNA was then  
265 obtained via reverse transcription of 1.5µg of total RNA using  
266 RevertAit™ First Strand cDNA Synthesis Kit (Fermentas).  
267 PCR was performed using 2µl of cDNA. The final PCR  
268 mixture contained 1x amplification buffer with 2.5 mM MgCl<sub>2</sub>,  
269 10mM dNTP Mix (Thermo Scientific), 0,25µM specific  
270 forward and reverse primers, 1 U Dream Taq (Thermo  
271 Scientific) in a final volume of 25µl.

272 Table 2 reports the list of genes whose expression was  
273 analyzed, their gene accession number, the sequence of forward  
274 and reverse specific set of primers and the length of the relative  
275 amplicons. All PCRs were performed using the following  
276 protocol: denaturation at 94°C for 30 sec; annealing at 55°C for  
277 30 sec; extension at 72°C for 30 sec, with 35 cycles The  
278 products of the RT-PCR were separated on agarose gel (1,5%  
279 P/V) in TAE buffer stained with 3,5µl ethidium bromide

280 (10mg/ml). Amplicons were visualized under UV light with a  
281 trans-illuminator and images acquired by a Canon digital  
282 camera. The analysis was repeated with two different replicates  
283 for each tissue sample. A semi-quantitative analysis of the  
284 expression of MSCs markers was performed evaluating the  
285 optical density of each positive band by means of the ImageJ  
286 image processing software normalized to the expression of the  
287 housekeeping gene GAPDH.

## 288 *2.6. Statistical analysis*

289 The results of the immunophenotypic characterization of MSC  
290 deriving from perivisceral and subcutaneous adipose tissue  
291 were compared. Data was expressed as mean± standard  
292 deviation (SD). The differences among the groups were  
293 considered statistically significant for  $P < 0.05$  and Mood's  
294 median test was made as non-parametric statistics analysis. All  
295 the tests were made using SPSS 16 IBM software.

## 296 **3. Results**

### 297 *3.1. Cell culture and isolation*

298 After 24 – 48 hours, cells were adherent to the surface of the  
299 flasks. Medium was changed after two-three days in order to  
300 eliminate non-adherent cells. During their growth, cells  
301 appeared as a homogeneous population of typical fibroblast-  
302 like cell morphology with elongated spindle like shape.

303            *3.2.Tri-lineage cell differentiation*

304    Cell cultures at P3 have were able to differentiate into  
305    osteogenic, adipogenic and chondrogenic lineages. A large  
306    number of cells contained intracellular lipid vacuoles stained  
307    with Oil Red O, confirming the adipogenic differentiation of  
308    sAT-MSC and pAT-MSC, following the appropriate  
309    stimulation in vitro. Cells stimulated with osteogenic induction  
310    medium formed aggregates and had numerous extracellular  
311    calcium deposits, as by with von Kossa staining confirmed the  
312    osteogenic differentiation of cells from both sources. The cell  
313    cultures treated with chondrogenic medium contained  
314    aggregates of proteoglycans stained in blue with Alcian Blue  
315    coloration. Control groups for each treatment showed no  
316    evidence of differentiation (Fig. 1).

317            *3.3.FACS analysis*

318    All antibodies tested on canine PBMC showed the expected  
319    reactivity (data not shown). For immunophenotypical analysis,  
320    the live population of MSC was gated in the scatter plot for  
321    further fluorescence intensity analysis in the histogram plot  
322    (Fig. 2).

323    Our data showed that MSC at P3 deriving from perivisceral and  
324    subcutaneous adipose tissue were positive for: CD29, CD44,  
325    CD73, CD90; and negative for CD34, CD45 and MHC-II

326 (Tables 3, 4). There was no significant difference in surface  
327 antigen expression between the two groups of MSC.

### 328 *3.4. Reverse transcription analysis of gene expression*

329 Expression analysis of a panel of genes consisting of CD90,  
330 CD73, CD105, CD45, CD34, CD44, CD13, CD29, CD31 and  
331 Oct-4 was performed on sAT-MSC and pAT-MSC at P3. Both  
332 populations were negative for CD45 and CD31. pAT-MSC  
333 were also negative for CD34 expression, while sAT-MSC  
334 showed weak expression. All other genes of the panel were  
335 expressed in both sAT-MSC and pAT-MSC. Semiquantitative  
336 analysis of marker profile, demonstrated a substantial  
337 equivalence between the two cell populations (Table 5).

## 338 **4. Discussion**

339 MSC-based treatment has been increasingly applied in  
340 veterinary medicine in the recent years. Several studies have  
341 reported the beneficial effects for different pathological states  
342 in dogs (Black et al., 2008, Hall et al., 2010, Pogue et al., 2013,  
343 Alamoudi et al., 2014, Marx et al., 2014, Penha et al., 2014,  
344 Villatoro et al., 2015, Perez-Merino et al., 2015, Kim et al.,  
345 2015 and Lee et al., 2015) , horses (Del Bue et al., 2008, Rich  
346 et al, 2014 and Govoni et al, 2015) and cats (Trzil, et al., 2015,  
347 Quimby, et al., 2016). Although the majority of the studies  
348 carried out contain a limited number of patients and often lack  
349 of appropriate controls, the results can be considered

350 encouraging for the set-up of clinical protocols to be applied in  
351 veterinary medicine.

352 For the reliability of research studies dealing with biological  
353 properties of MSC and for the safety of clinical treatments  
354 based on these cells, it is necessary to have accurate cell  
355 characterization. The availability of several possible tissue  
356 sources, different methods of cell culture, expansion and  
357 handling, as well as a variety of possible therapeutic  
358 approaches, represent a limit to the correct evaluation of the  
359 healing potential of these cells.

360 Following the basic criteria for the characterization of human  
361 MSC (Dominici et al., 2006), equivalent MSC derived from  
362 laboratory and domestic animals were demonstrated to have  
363 fibroblast-like shape, ability to differentiate into osteogenic,  
364 chondrogenic and adipogenic lineages and have a determinate  
365 cell surface antigen pattern. However, the lack of species-  
366 specific antibodies has been a major drawback towards the full  
367 and accurate immunophenotypic characterization of animal  
368 derived MSC. Therefore, the first aim of our study was to select  
369 a panel of species-specific antibodies for the evaluation of cell  
370 surface CD markers expression in canine adipose tissue derived  
371 MSC that could be routinely used for the cell characterization  
372 prior to their use.

373 A further aim was to compare the marker expression of MSC  
374 derived from subcutaneous and perivisceral adipose tissue.  
375 Indeed, the characterization of these two populations of MSC  
376 would be of practical relevance for their clinical use.  
377 Subcutaneous adipose tissue is an easily available source of  
378 MSC. Samples of a few grams of fat tissue can be collected  
379 quickly and safely during surgery in dogs of different sizes,  
380 avoiding the potential risk associated with abdominal surgery  
381 or bone marrow aspiration.

382 Cells from both tissue sources had a similar fibroblast-like  
383 morphology, were able to adhere to plastic surface, grew in  
384 monolayer and demonstrated the capacity to differentiate in  
385 osteogenic, chondrogenic and adipogenic lineages when  
386 stimulated with appropriate induction medium. A previous  
387 study reported similar results (Guercio et al., 2013), but lacked  
388 the immunophenotypic characterization of the cell population.  
389 Thus, in the present study, we chose to determine the  
390 expression of a panel of cell surface CD markers (CD29, CD34,  
391 CD44, CD45, CD90, CD73 and MHC-II), typical for the MSC  
392 (Dominici et al., 2006) using anti-canine antibodies. CD 105 -  
393 one of the three surface markers that define human MSC  
394 (Dominici et al., 2006), was not taken in consideration in our  
395 study since we were not able to find any commercially  
396 available anti-CD105 canine antibodies.

397 Antibody reactivity was confirmed by flow cytometry of canine  
398 PBMC that served as a positive control. Interestingly, canine  
399 AT-MSC derived from subcutaneous and perivisceral adipose  
400 tissue showed a similar immunophenotypic pattern, which from  
401 a practical point of view indicates that both tissues can be used  
402 as a valid source for the isolation of MSC. RT-PCR analysis  
403 confirmed the results obtained with flow cytometry, as the two  
404 cell populations demonstrated a similar qualitative pattern of  
405 expression.

406 The comparison of the immunophenotypical profile of AT-  
407 MSC among canine, human and other species adipose tissue  
408 derived MSC would be of interest, as the dog is considered a  
409 suitable animal model for the study of human diseases.

410 In comparison to laboratory animals, canine anatomy and  
411 physiology, and the prevalence of natural occurring diseases  
412 with similar pathogenesis, more closely resemble humans.  
413 Dogs have a longer life-span, live in environments similar to  
414 humans and therefore are exposed to different external factors  
415 that are part of the aetiology of common diseases and  
416 conditions such as diabetes, obesity and tumors. The clinical  
417 follow-up is similar and there is a wide range of imaging  
418 techniques developed for veterinary patients (Volk and Theoret,  
419 2013).

420 A complete overlap of marker expression between human MSC  
421 has yet to be demonstrated due to the lack of an extensive cell  
422 characterization in some species. However, similarities can be  
423 found between MSC derived from domestic and laboratory  
424 animals and humans. Most of the markers analyzed in this  
425 study share a similar distribution in the different species, with  
426 the exception of CD73. The identical expression of CD29,  
427 CD34, CD44, CD45, CD90 and MHC-II suggest that *in vitro*  
428 cultured canine MSC share most of their characteristics with  
429 human MSC. The unique difference found was in the  
430 expression of CD73, one of the three positive markers proposed  
431 for defining hMSC ( $\geq 95\%$ ) (Dominici et al., 2006).  
432 Interestingly, we report here for the first time that the  
433 expression of CD73 is lower in an animal species compared to  
434 humans (Table 6). This would suggest that there is a slightly  
435 different immunophenotypic profile that should be taken in  
436 consideration for the correct interpretation and characterization  
437 of AT-MSc in veterinary patients.

438 Since bone marrow is commonly used in veterinary medicine  
439 for the isolation of MSC, we also compared our results with the  
440 immunophenotypical characteristics previously described for  
441 bone marrow derived MSC (BM-MSc) (Takemitsu et al.,  
442 2012) (Table 7). Both profiles are similar in terms of CD29,  
443 CD44 as positive markers and CD34, CD45 and MHC-II as  
444 negative markers. A difference exists in the expression of

445 CD73 and CD90, which appears to be lower in BM-MSc.  
446 However, the authors used non-canine specific antibodies for  
447 the analysis, which can have an influence on the interpretation  
448 of the percentage of expression. Altogether, the results  
449 presented in the table indicate a quite similar profile between  
450 canine adipose tissue and bone marrow derived MSC.

## 451 **5. Conclusions**

452 In conclusion, the present study reports the evaluation of a  
453 panel of 7 primary antibodies suitable for the flowcytometric  
454 characterization of canine MSC isolated from adipose tissue.  
455 Marker expression was the same in subcutaneous-derived and  
456 perivisceral-derived fat tissue. The substantial equivalence  
457 between the two sources of MSC has practical consequences in  
458 the clinical application of cell therapy, giving the veterinarian  
459 the opportunity to choose the source depending on the needs of  
460 each patient.

## 461 **Conflict of interest statement**

462 This research did not receive any specific grant from funding  
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466 Veterinary Clinic “Jenner”, Parma, led by Dr. Emanuele  
467 Cabibbo for the help in collecting adipose tissue samples.

468 **Table 1. Description of the panel of antibodies**

<b>Target cell marker</b>	<b>Clone</b>	<b>Reactivity</b>	<b>Production company</b>
<b>CD 29</b>	TS2/16	Human;Dog; Bovine	BioLegend
<b>CD 34</b>	1H6	Dog	eBioscience
<b>CD 44</b>	YKIX337.8	Dog	eBioscience
<b>CD 45</b>	YKIX716.13	Dog	eBioscience
<b>CD 73</b>	Polyclonal	Human;Mouse;Rat; Chicken	Dog; Bioss
<b>CD 90</b>	YKIX337.217	Dog	eBioscience
<b>MHC-II</b>	YKIX337.8	Dog	eBioscience

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487 **Table 2. Markers used for the evaluation of cell surface**  
 488 **markers expression of MSC by RT-PCR**

<b>Markers</b>	<b>Accession Number</b>	<b>Primers</b>	<b>Amplicon size</b>
<b>CD 13</b>	NM_0011 46034.1	Fw: GGTCCTTACCATCACCT GGC Rv: CCTAAGGCCATCCATC GTCC	335bp
<b>CD 29</b>	XM_0056 16949.1	Fw: AGGATGTTGACGACTG CTGG Rv: ACCTTTGCATTTCAGTGT TGTGC	356bp
<b>CD 31</b>	XM_8483 26	Fw: GCCCGAAGTTCACCTCTC AAG Rv:CACTCCTTTGACCCA CACCT	410bp
<b>CD 34</b>	NM_0010 03341.1	Fw: GAGATCACCCCTAACGC CTGG Rv: GGCTCCTTCTCACACAG GAC	383bp
<b>CD 44</b>	NM_0011 97022.1	Fw: CCCATTACCAAAGACC ACGA Rv: TTCTCGAGGTTCCGTGT CTC	408bp
<b>CD 45</b>	XM_0056 22282.1	Fw: TGTTTCCAGTTCTGTTT CCCCA Rv: TCAGGTACAAAGCCTT CCCA	432bp
<b>CD 73</b>	XM_5322 21.4	Fw: GATGGGAAAGGCAAGA GGCT Rv: TTCCTGGCATCTTGCTA CGG	317bp
<b>CD 90</b>	NM_0012 87129.1	Fw: AAGCCAGGATTGGGGA TGTG Rv: TGTGGCAGAGAAAGCT CCTG	285bp
<b>CD 105</b>	XM_0056 25330.2	Fw: GCTGAGGACAGAGATG	421bp

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		ACCA	
		Rv:	
		CACGGAGGAGGAAGCT	
		GAAG	
<b>Oct-4</b>	<b>XM_5388</b>	<b>Fw:</b>	<b>286bp</b>
	30.1	AAGCCTGCAGAAAGAC	
		CTG	
		Rv:	
		GTTCGCTTTCTCTTTCG	
		GGC	

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511 **Table 3. Flow cytometric analysis of adipose tissue derived**  
 512 **MSC**

<b>Markers</b>	<b>sAT-MSC<sup>a</sup></b>	<b>pAT-MSC<sup>b</sup></b>
<b>CD 29</b>	99.5%±0.6	99.2%±1.5
<b>CD 34</b>	0.5%±1	0.25%±0.5
<b>CD 44</b>	78%±17	76.7%±18
<b>CD 45</b>	0.25%±0.5	0.5%±0.6
<b>CD 73</b>	14%±12.3	17%±14
<b>CD 90</b>	89%±6.7	79.5%±7.1
<b>MHC-II</b>	4.5%±6.3	4.5%±6.4

513 a and b: Data are displayed as percentages expressed as mean ± SD. Mood's median

514 test was applied and no statistical difference for P<0.05 was found.

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535 **Table 4. Summary of cell surface markers expression**  
 536 **measured by flow cytometry analysis**

Cells	CD29	CD34	CD44	CD45	CD73	CD90	MHC-II
sAT- MSC	+++ <sup>b</sup>	- <sup>c</sup>	+++ <sup>b</sup>	- <sup>c</sup>	++ <sup>a</sup>	+++ <sup>b</sup>	- <sup>c</sup>
pAT- MSC	+++ <sup>b</sup>	- <sup>c</sup>	+++ <sup>b</sup>	- <sup>c</sup>	++ <sup>a</sup>	+++ <sup>b</sup>	- <sup>c</sup>

537 **a** ++ (10-40% positive cells)

538 **b** +++ (>40% positive cells)

539 **c** - (<5% positive cells).

540 Different groups are classified as described by Screven et al 2014

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559 **Table 5. Gene expression analysis of pAT-MSC and sAT-**  
 560 **MSC using semi-quantitative RT-PCR**

Cell marker	pAT-MSC	sAT-MSC
CD90	+++ <sup>d</sup>	+++ <sup>d</sup>
CD73	++ <sup>c</sup>	++ <sup>c</sup>
CD105	++ <sup>c</sup>	++ <sup>c</sup>
CD45	- <sup>a</sup>	- <sup>a</sup>
CD34	- <sup>a</sup>	+ <sup>b</sup>
CD44	+++ <sup>d</sup>	+++ <sup>d</sup>
CD13	+++ <sup>d</sup>	+++ <sup>d</sup>
CD29	+++ <sup>d</sup>	+++ <sup>d</sup>
CD31	- <sup>a</sup>	- <sup>a</sup>
Oct-4	+ <sup>b</sup>	+ <sup>b</sup>

561 **a** – (not expressed)  
 562 **b** + (<25% of GAPDH signal)  
 563 **c** ++ (25-50% of GAPDH signal)  
 564 **d** +++ (>50% of GAPDH signal)

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581 **Table 6. Comparison of the immunophenotypic profile of**  
 582 **adipose derived MSC from multiple species**

Species	Marker expression						
	CD 29	CD 34	CD 44	CD 45	CD 73	CD 90	MHC-II
<b>Human<sup>e</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Mouse<sup>f</sup></b>	+++ <sup>c</sup>	/ <sup>d</sup>	+++ <sup>c</sup>	- <sup>a</sup>	++ <sup>b</sup>	+++ <sup>c</sup>	/ <sup>d</sup>
<b>Rat<sup>g</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	/ <sup>d</sup>	- <sup>a</sup>	/ <sup>d</sup>	/ <sup>d</sup>	/ <sup>d</sup>
<b>Dog<sup>h</sup></b>	+++ <sup>c</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	++ <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Horse<sup>i</sup></b>	/ <sup>d</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>
<b>Cat<sup>j</sup></b>	/ <sup>d</sup>	- <sup>a</sup>	+++ <sup>c</sup>	- <sup>a</sup>	/ <sup>d</sup>	+++ <sup>c</sup>	/ <sup>d</sup>

583 **a** - (<5% positive cells)

584 **b** ++ (10-40% positive cells)

585 **c** +++ (>40% positive cells)

586 **d** / (not known)

587 Different groups are classified as described by Screven et al 2014

588 **e** (Dominici et al., 2006)

589 **f** (Taha and Hedayati, 2010) (Laschke et al., 2013)

590 **g** (Lotfy et al., 2014) (Tapp et al., 2008)

591 **h** *our results*

592 **i** (de Mattos Carvalho et al., 2009)(Pascucci et al., 2011)(Barberini et al., 2014)

593 **j** (Kono et al., 2014)

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606 **Table 7 Comparison of the expression of the**  
 607 **immunophenotypic profile between MSC deriving from**  
 608 **subcutaneous adipose tissue, perivisceral adipose tissue and**  
 609 **bone marrow**

Markers	sAT-MSC	pAT-MSC	BM-MSC <sup>a</sup>
<b>CD 29</b>	99.5%±0.6	99.2%±1.5	98.41±0.53
<b>CD34</b>	0.5%±1	0.25%±0.5	0.88±0.21
<b>CD 44</b>	78%±17	76.7%±18	98.90±0.25
<b>CD 45</b>	0.25%±0.5	0.5%±0.6	0.24±0.07
<b>CD 73</b>	14%±12.3	17%±14	0.0081±0.01
<b>CD 90</b>	89%±6.7	79.5%±7.1	19.10±2.10
<b>MHC-II</b>	4.5%±6.3	4.5%±6.4	2.85±1.35

610 <sup>a</sup>Takemitsu et al., 2012

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626 **Figure 1** In vitro tri-lineage cell differentiation

627 Photomicrographs of canine perivisceral adipose tissue derived  
628 MSC- (pAT-MSC: **b, f, j**) and canine subcutaneous adipose  
629 tissue derived MSC (sAT-MSC: **d, g, l**), after 21 days of  
630 culture in adipogenic (**b, d**), chondrogenic (**f, h**), osteogenic  
631 (**j,l**) induction medium. Parallely a control culture of pAT-MSC  
632 (**a, e, i**) and sAT-MSC (**c, g, k**) was grown for 21 days in  
633 DMEM. Adipogenic differentiation is evidenced with the  
634 presence of intracellular vacuoles colored in red (black arrow)  
635 with Oil Red O staining, in pAT-MSC (**b**) and sAT- MSC (**d**),  
636 which are absent in control groups (**a,c**) (40X, scale bar  
637 200µm). Alcian blue staining indicated the presence of  
638 aggregates of proteglycans present in treated pAT-MSC (**f**) and  
639 sAT-MSC (**h**), and their absence in the control cultures (**e,h**)  
640 (10X, scale bar 100µm). Osteogenic differentiation was  
641 indicated with extracellular calcium aggregates stained with  
642 von Kossa coloration in pAT-MSC (**j**) and sAT-MSC (**l**)  
643 stimulated with ostegenic medium. Control groups did not  
644 contain any calcium aggregates (**i, k**) (10X, scale bar 100um).

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646 **Figure 2** Flow cytometry analysis of the expression of cell  
647 surface markers on sAT-MSC and pAT-MSC

648 The expression of cell surface markers is presented in two  
649 panels. The upper panel (a) contains data regarding the MSC

650 deriving from subcutaneous adipose tissue and the low panel  
651 (b) data about MSC deriving from perivisceral adipose tissue.  
652 Live cell populations were gated in forward and side scatter for  
653 further analysis. Each histogram contains two peaks. The  
654 shaded red peak represents the actual expression of the markers  
655 for each cell group, on the other hand the transparent one is the  
656 negative control.

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Figure 1  
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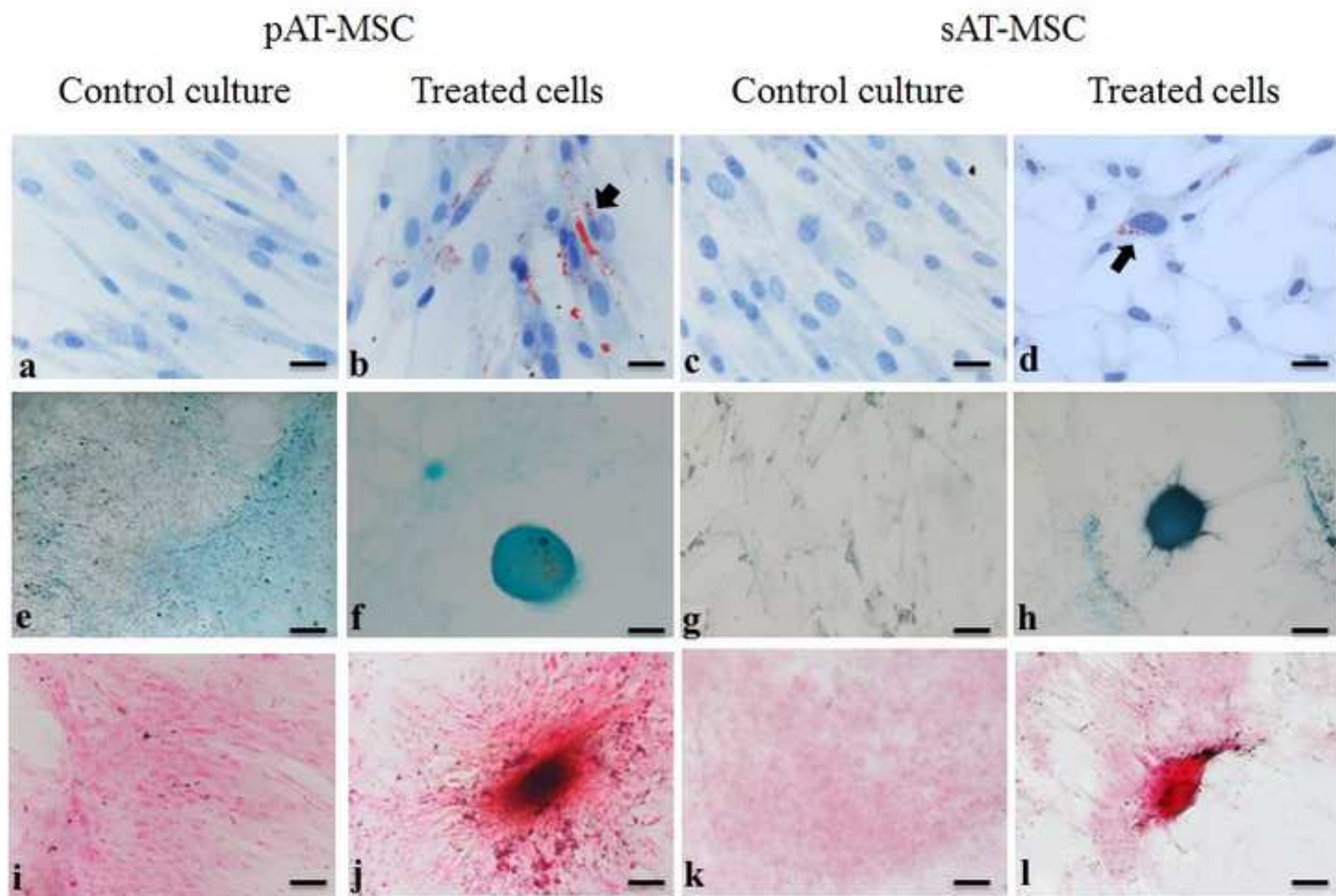
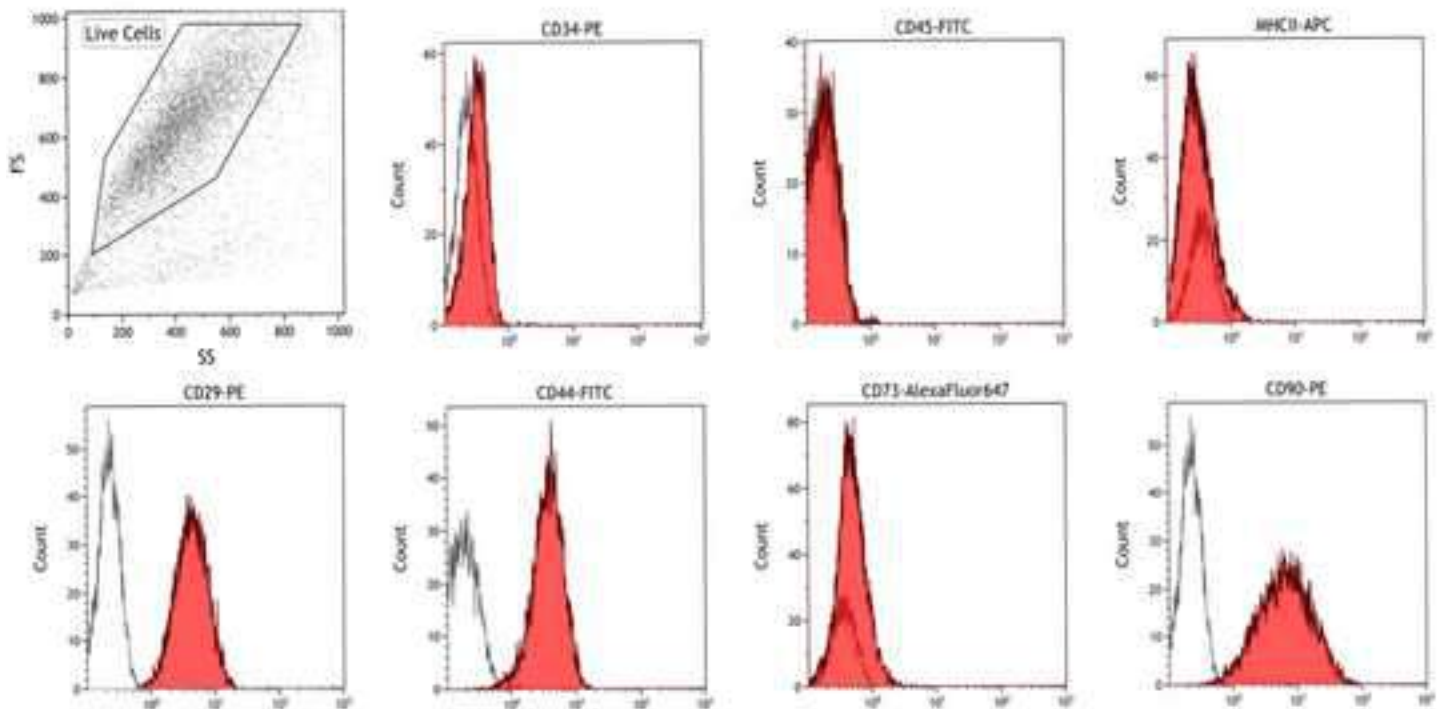


Figure 2

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### Expression of cell surface markers on sAT-MSC measured by flow cytometry



### Expression of cell surface markers on pAT-MSC measured by flow cytometry

