 doi:10.20944/preprints201901.0082.v2

Article

Characterization of collagens fibers (I, III, IV) and elastin in the extracellular matrix of normal and neoplastic canine prostatic tissues

Luis Gabriel Rivera Calderón [1], Priscila Emiko Kobayashi [2] Rosemeri Oliveira Vasconcelos [1], Carlos Eduardo Fonseca-Alves [3] and Renee Laufer-Amorim [2,*]

[1] Department of Veterinary Pathology, School of Agricultural and Veterinarian Sciences, São Paulo State University (Unesp), Jaboticabal, São Paulo, Brazil; lgriveramvz@gmail.com (LGRC); rosevasc@fcav.unesp.br (ROV)

[2] Department of Veterinary Clinic, School of Veterinary Medicine and Animal Science, São Paulo State University (Unesp), Botucatu, São Paulo, Brazil; renee.laufer-amorim@unesp.br (RLA); pri_kobayashi@hotmail.com (PEK)

[3] Department of Veterinary Surgery and Anesthesiology, School of Veterinary Medicine and Animal Science, São Paulo State University (Unesp), Botucatu, São Paulo, Brazil; carlos.e.alves@unesp.br

* Correspondence: renee.laufer-amorim@unesp.br; Tel.: +55-14-3880-2076

Abstract: Collagen (Coll) is the most common protein in the extracellular matrix, responsible for providing tissue structure and support. In some types of cancer, including prostate cancer (PC) Coll deregulation was described and related to tumor progression and metastasis. This study aimed to investigate Coll-I, III, IV and elastin in canine normal prostate and PC, using Picrosirius red (PSR) and Immunohistochemical (IHC) analysis. Eight normal prostates and 10 PC from formalin-fixed, paraffin-embedded samples were used. Collagen fibers area was analyzed with ImageJ software. The distribution of Coll-I and Coll-III was approximately 80% around prostatic ducts and acini, 15% among smooth muscle and 5% around in blood vessels, in both normal prostate and PC. Immunostaining for Coll-IV was observed in the basal membrane of prostate acini, smooth muscle, blood vessels, and never fibers of normal and PC samples. Elastic fibers were found in the septa dividing the lobules and around the prostatic acini of normal samples. A high amount of elastic fibers was observed around the ducts and the urethra in normal and PC. The distribution and area percentage of staining for collagen are similar in normal and neoplastic canine prostate when analyzed with PSR and IHC.

Keywords: dog; prostatic tissue; extracellular matrix; picrosirius; immunohistochemistry

1. Introduction

Cancer is the second leading cause of mortality worldwide. In men, prostate cancer (PC) is the third most common malignant neoplasia (after non-melanoma skin cancer and lung cancer) [1]. In advanced stage, human PC often shows metastasis to bones and resistance to anti-androgen treatment [2]. Similar to the men, dogs spontaneously develop PC [3, 4]. In dogs, PC it is a very aggressive and highly metastatic disease [5]. Usually, bone metastasis is diagnosed at a late stage of highly aggressive tumor subtypes [3]. Due to similarities in the clinical and pathologic aspects of PC in both species, some authors suggest that the dogs may be considered a good model for the study of human PC [4, 5, 6, 7].

Recently, has been demonstrated in the human PC an interaction between the tumor cells and the proteins of extracellular matrix (ECM). The ECM fibers play an important role in PC development

 doi:10.20944/preprints201901.0082.v2

and progression [8, 9]. The ECM is a complex network of macromolecules [10]. The major constituents of ECMs are proteoglycans and fibrous proteins (collagen, elastin, fibronectin and laminin) [11]. Collagen (Coll) is the most common protein of the ECM [10]. The main collagen function is to provide structure, support and tensile strength, as well as, regulation of cell adhesion, chemotaxis, migration and direct tissue development [12]. In some human cancers, such as breast, colon and prostate, occurs a formation of abundant collagenous stroma (reactive stroma) in their tumor microenvironment (TME), responsible for the tumor metastatic process [8, 13, 14]. High density of type I collagen (Coll-1) and degradation of type IV collagen (Coll-IV) are frequently observed in solid cancer, associated with metastasis [9, 15-18]. In the veterinary medicine, few studies were conducted to understand the relationship between cancer and the collagens fibers, compared to human medicine [19]. Due the lack of information regarding tissue stroma in canine PC, this study aimed to characterize and compare the collagen fibers and elastin in the normal prostate and canine PC, using PSR and immunohistochemical test.

2. Materials and Methods

2.1. The Subjects

Eight canine normal prostates and 10 PC were retrieved from the archives of the Veterinary Pathology Service, FMVZ, UNESP, Botucatu, SP, Brazil. The prostates were collected from necropsies from animals that had an interval between death and necropsy less than 6 hours. Formalin-fixed paraffin-embedded (FFPE) samples from canine prostatic tissue were sectioned for histological diagnosis, which was performed by three pathologists (LGRC, CEFA, PEK), at the same time, in a multi-head microscopy. The histopathological classification was performed according to the human WHO from Tumors of the Urinary System and Male Genital Organs [20], which was recently adapted to canine PC [4]. (Supplementary Table 1). This study was approved by the institutional committee for the use of animals in research (#10.162/2016).

PC samples (10/10) were from intact male dogs, with age raging 8 up to 12 years. Six out of 10 samples were from mixed breed dogs, two cases (2/10) were from a German Shepherd dog, one case (1/10) from a Brazilian Mastiff dog and the other one from a Poodle (1/10). Regarding the clinical signs, five out of 10 patients showed tenesmus, three dogs had lameness (3/10) and two dogs (2/10) had loss of appetite. Five out of 10 patients had metastasis at the diagnosis and all dogs (10/10) died due to PC.

2.2. Picrosirius (PSR)

The slides were deparaffinized in xylene and rehydrated in alcohol. After, PSR staining was performed using a commercial kit (HistokitTM, Easypath, SP, Brazil), according to manufacturer's instructions. The slides were examined in an optical microscopy with polarized light (Axio Imager A1, Zeiss®, Germany). The collagen fibers that presented red-orange birefringence were considered type I, while the collagen fibers with green birefringence were interpreted as type III (Coll-III) [21].

2.3. Immunohistochemistryn (IHC)

The slides were subject to immunohistochemical using the peroxidase method. The antibodies, antigen retrieval, dilutions and incubation period are described in the Table 1. Endogenous peroxidase activity was inhibited with 4% hydrogen peroxide in methanol for 10 min at room temperature (RT). Then, the slides were treated with protein block serum-free for 15 min RT (Dako, Carpinteria, CA, USA). In each step, the slides were washed with Tris-buffered saline (pH 7.4). A LSAB system was used as secondary antibody; applied for 1 hour at RT, according to manufacturer's instructions (Dako, Carpinteria, CA, USA). Peroxidase activity was reveled with 3',3'-Diaminobenzidinechromogen (DAB, Substrate System, CA, Dako). For the counterstained, Harris's hematoxylin was used. As negative control, primary antibodies were replaced by Tris-buffered saline solution. A canine normal skin tissue was used as positive control tissue for all antibodies.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2019 doi:10.20944/preprints201901.0082.v2

Table 1. Primary antibodies, retrieval antigen, dilution and incubation period used in the IHC test.

Primary antibody	antigen Retrieval	Dilution	Incubation Period
Collagen I, rabbit, Novotec	Citrate buffer pH 6,0, microwave, twice for 5 min	1:1000	Overnight at 4°C
Collagen III, rabbit, Novotec	Pepsin 2%, pH 1,4 in oven for 10 min at 60°C after for 30 min at 37°C.	1:1000	Overnight at 4°C
Collagen IV, rabbit, Biorbyt	Pepsin 2%, pH 1,4, in oven for 10 min at 60°C after for 30 min at 37°C.	1:1000	Overnight at 4°C
Elastin (BA-4), mouse, Santa Cruz.	Citrate buffer pH 6,0, pressure cooker (Pascal®, Dako, Carpinteria, CA, USA)	1:100	Overnight at 4°C

2.4. Interpretation of PSR and IHC staining

In the PC samples, areas with a higher percentage of neoplastic cells and minimal density of inflammatory cells were selected. In the normal samples, it was collected samples from the peripheral region of the prostatite gland, avoiding areas close to the median septa, according to Ruetten et al. [22]. For normal and PC samples, it was captured five fields (20x magnification) with a digital camera (Axioncam MRc, Zeiss® Vision, Germany) for each protein and PSR. The stained areas were analyzed with Image J 1.49v software (National Institutes of Health, USA) and were assessed by setting a threshold, using the Image J threshold tool in according to the procedure described by Bauman et al., [23]. Briefly, the staining distribution and intensity of the collagens and elastic fibers were evaluated in both normal canine prostate and PC. For PSR staining, it was used a manual thresholding of hue (121-179), saturation (20-255), and brightness (10-255) values in ImageJ [23]. For each marker in immunohistochemistry, we established a threshold values as follow: Coll-I: hue (0-170), saturation (69-255), and brightness (90-181), Coll-III: hue (111-176), saturation (10-98), and brightness (37-157), Coll-IV: hue (65-255), saturation (90-178), and brightness (101-255) and elastin: hue (0-146), saturation (0-175), and brightness (0-209).

2.5. Data analysis

Descriptive statistics was used to define the median and percentile of Coll-I, Coll-III and elastin in normal and canine PC. For statistical propose, we grouped samples with Gleason score 6 and 8 and compared with samples with Gleason score 10. Mann-Whitney U test was applied to compare the area percentage among normal and canine PC. Statistical significance was set at $p< 0.05$. All statistical analysis was done using GraphPad Prism 8 (GraphPad Software Inc. La Jolla, CA).

3. Results

Five out of 10 PC samples had Gleason 8 (5/10), four had Gleason score 10 (4/10) and one Gleason score 6 (1/10). The mean survival time was 152.1 days (±134.8). All prostatic samples (18/18) stained with PSR and the Coll-I was more abundant than Coll-III (Figure 1). The median expression of Coll-I by PSR in normal samples was 1.89 (1.196 - 3.839) and in PC samples was 2.24 (1.358 – 2.834). There was no statistical difference of Coll-I expression between normal and PC samples. Regarding the IHC for Coll-I, we also identified a higher proportion of Coll-I compared to Coll-III (Figure 1). The median expression of Coll-I in normal samples by IHC was 4.73 (1.367 – 8.414) and 6.18 (1.577 – 17.572) for PC samples. We identified a positive correlation of Col-I expression between PSR and IHC techniques ($R=0.6185$; $P=0.05$). Thus, although the results are numerically different for both techniques, there is a correlation of the results. Besides that, we evaluated the distribution of the Coll-I thought the normal prostate. Approximately 80% of the Coll-I was located surrounding prostatic ducts and acini, 15% among smooth muscle and 5% around blood vessels (Figure 1). We also did not find statistical difference of Coll-I immunoexpression between normal and PC samples. Comparing Coll-I expression between samples with Gleason score 10 and 8/6, we did not find statistical difference ($P=0.761$)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2019 doi:10.20944/preprints201901.0082.v2

Regarding Coll-III expression, we identified positive stain in all prostatic samples (18/18) for both techniques. PC samples showed a higher expression of Coll-III than normal samples by PSR (P=0.01). The median expression for Coll-III expression in normal samples was 1.64 (0.975 – 3.329) and 2.25 (1.067 – 3.605) for PC samples. We identified a higher Coll-III expression in PC samples compared to normal samples (P=0.05) by IHC. We identified a strong positive correlation (R=0.7805; P=0.007) of Coll-III expression between PSR and IHC techniques. Thus, samples with high Coll-III by PSR technique also showed a higher Col-III expression by IHQ. We also qualitatively assessed the Coll-III distribution among the prostatic tissues. In both normal and PC samples, 80% of the Coll-III was located surrounding prostatic ducts and acini, 15% among smooth muscle and 5% around blood vessels (Figure 1). Table 2 shows the median, 25% percentile and 75% percentile values of Coll-I and Coll-III according to the diagnosis group and test applied. There was no statistical difference regarding the Coll-III expression and the Gleason score (P=0.0654).

Table 2. Median, 25% percentile and 75% percentile values of area percentage staining for Coll-I and Coll-I in the normal and canine PC, according to the method used.

		PSR test				IHC test			
		25%	**Median**	**75%**	**p**	**25%**	**Median**	**75%**	**p**
	N	1.25	1.89	2.27		2.85	4.73	8.03	
Coll-I	PC	2.09	2.24	2.43	0.1298	3.31	6.18	8.56	0.3159
	N	1.33	1.64	2.06		1.81	3.22	5.03	
Coll-III	PC	1.68	2.25	3.11	0.001	3.72	5.07	6.44	0.05

Coll-I: Collagen I, Coll-III: Collagen III, N: Normal, PC: Prostatic carcinoma.

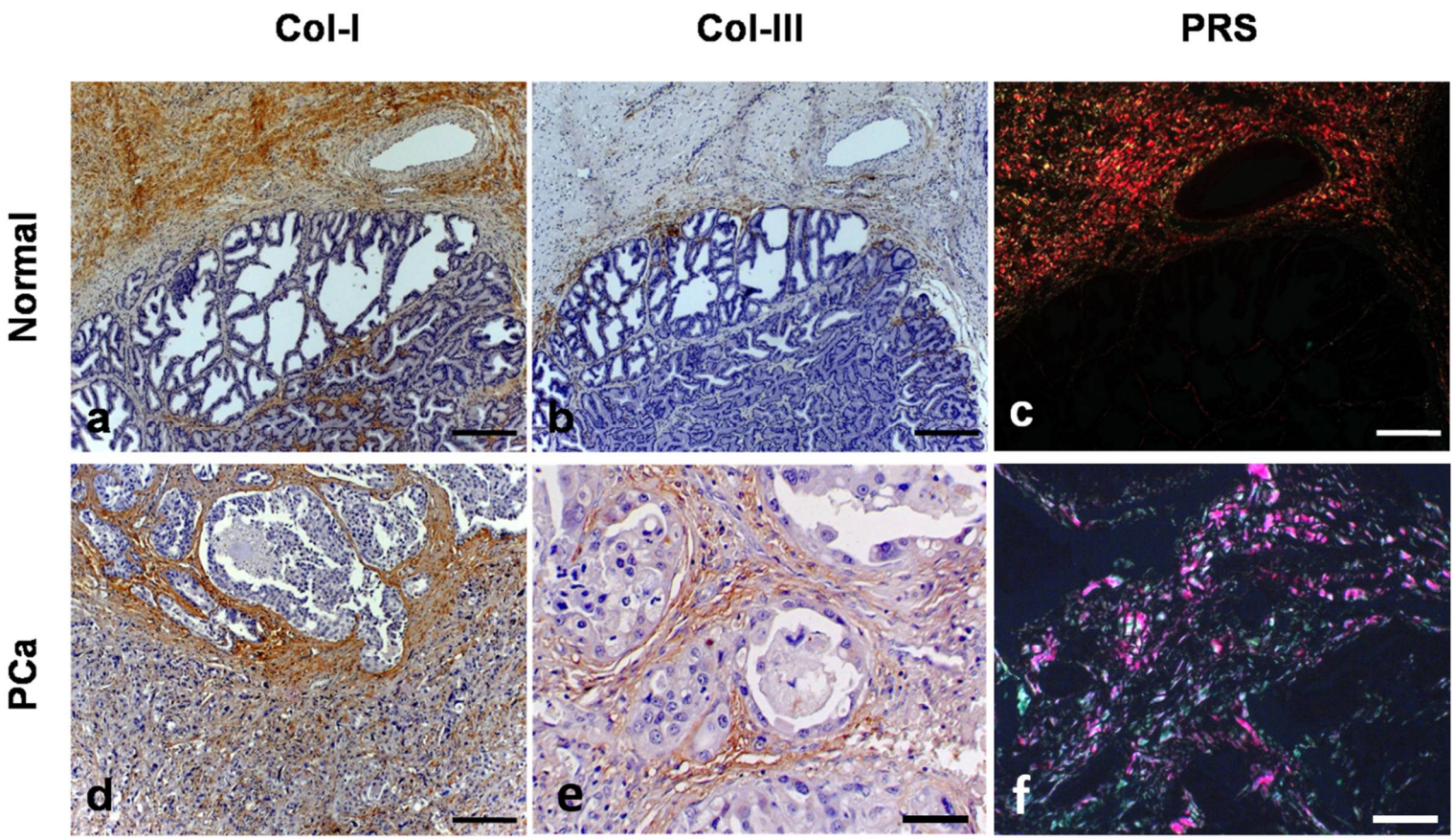
Immunostaining for Coll-IV was observed in the basal membrane (BM) of prostate acini, smooth muscle, blood vessels, and never fibers of normal and PC samples, although it was discontinuous (Figure 2). It was observed a Coll-IV immunostaining surrounding continuously the blood vessels in both normal and PC samples. The distribution of Coll-IV was approximately 70% in the BM, 15% in smooth muscle, 10% in blood vessels BM and 5% in nerve fibers in both groups. When we compared the normal prostate with PC samples, we did not find statistical difference, concerning Coll-IV expression (P=0.2722). However, it was identified absence of Coll-IV immunostaining in the tumors with Gleason score 10 compared to tumors with Gleason score 6 and 8 (P=0.0095) (Figure 2). The results of Coll-IV expression are described in Table 3.

Table 3. Median, 25% percentile and 75% percentile values of area percentage staining for Coll-IV and elastin in the normal prostate and canine PC samples.

	Group	**IHC test**			
		25%	**Median**	**75%**	**p**
	Normal	1.11	1.41	1.72	0.2135
Coll-IV	PC	0.58	1.14	1.61	
	Normal	0.25	0.26	0.42	0.00229
Elastin	PC	0.28	0.43	0.51	

Immunostaining for elastin was observed with similar intensity and distribution than Coll-IV, around blood vessels in normal tissues and PC. Elastic fibers were found in the septa dividing the lobules and around the prostatic acini of normal samples. A high amount of elastic fibers was observed around the ducts and the urethra in normal and canine PC (Figure 2). It was identified a higher expression of Elastin in PC samples compared to normal samples (P=0.00229). There was no statistical difference comparing Gleason score 10 with Gleason 6 and 8 samples (P=0.897).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2019 doi:10.20944/preprints201901.0082.v2



168

169 **Figure 1.** The immunohistochemistry and PSR stain in normal tissue and canine PC. a: immunostaining of Coll-I in the stroma of normal prostate (case No. 3). b:
170 immunostaining of Coll-III in the stroma of the normal prostatic tissue (case No. 3). c: PSR staining observed in an optical microscopy with polarized light, the collagens
171 fibers present red-orange birefringence (Coll-I) and green birefringence (Coll-III) in a smaller amount (case No. 3). d: immunostaining of Coll-I in the stroma of prostatic
172 neoplastic tissue (case No. 11). e: immunostaining of Coll-III in the stroma of canine PC (case No. 11). f: PSR staining in the canine PC with similar amounts of Coll-I and
173 Coll-III (case No. 11).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2019 doi:10.20944/preprints201901.0082.v2

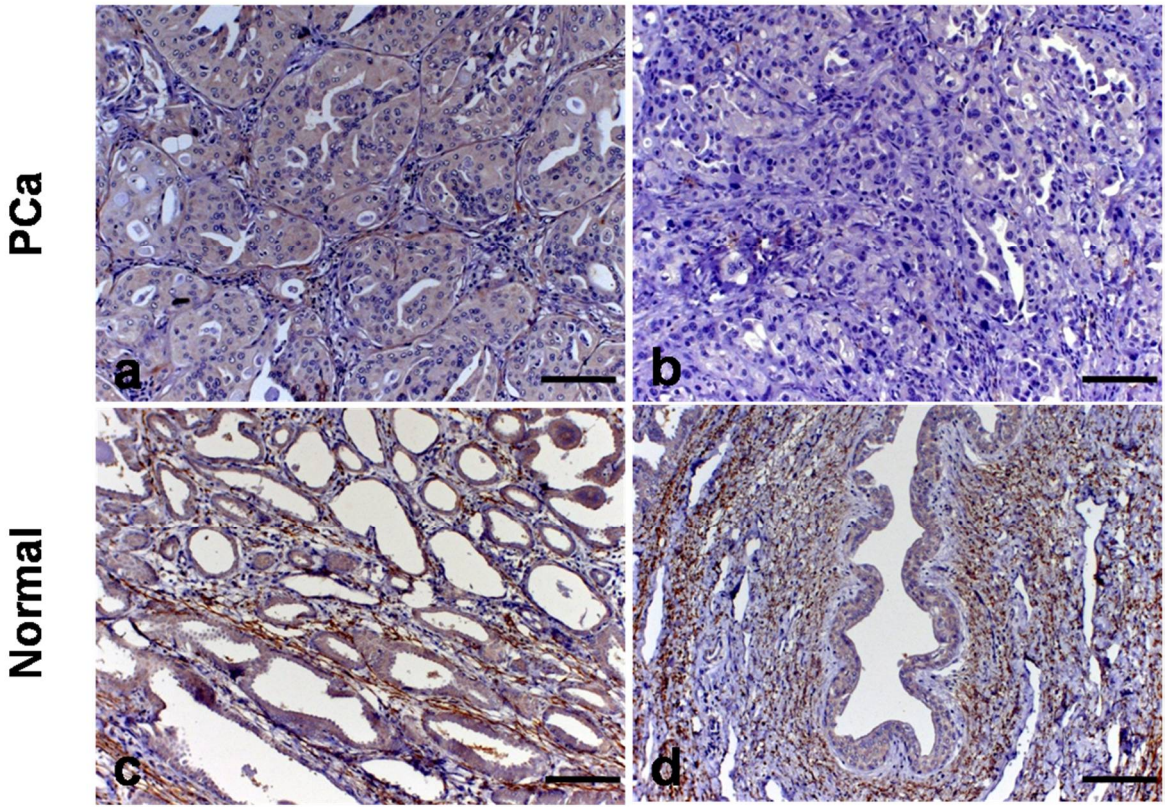


Figure 2. Immunostaining for Coll-IV and elastin in canine prostatic tissue. a: Coll-IV immunostaining in the basal membrane of canine PC with cribiforme pattern (case No. 15). b: Absence of Coll-IV immunostaining in canine PC with solid pattern (case No. 12). c: Elastin fibers around the prostatic acini of normal samples (case No. 5). d. High amount of elastin fibers around the urethra (case No. 5).

4. Discussion

In cancer, the EMC is a network of macromolecules that allow the cellular evasion towards the defense of the organism, besides helping in their metastatic process [10]. Collagens fibers are important components of ECM remodeling in the TME, actually is know that their degradation and redeposition promote tumor infiltration, angiogenesis, invasion and migration [11]. In this study, we identified and characterized collagen and elastin fibers in the normal prostate and canine PC using PSR and IHC tests. This research also compared the correlation of both tests to identify Coll-I and III expression. Coll-I expression was not statistically different when compared normal prostates and canine PC samples using both techniques. Although PSR is less sensitive for staining of collagen fibers, the positive correlation between these two techniques, allows us to suggest that PSR is cheaper and routinely used in some histology laboratories, and can be a good choice. In humans, Bauman et al., [23] evaluated the Coll-I content in normal prostates and benign prostatic hyperplasia (PH) by PSR staining, with no statistical difference. We did not find studies evaluating collagens fibers with PSR and IHC simultaneously, in both human and canine PC. Regarding the immunostaining of Coll-I, statistical difference it was also not identified comparing normal and PC samples. However, in PC samples, we identified a higher median of Coll-1 expression. The lack of statistical difference can be related to the low number of cases but also corroborates with Bauman et al., [23]

Wegner et al., [24] performed a study with PSR in the prostate gland of C57BL/6J mice. They found that fluorescent PSR imaging was more sensitive than polarized light for identify the collagen fibers. In addition, Fluorescent PSR imaging was compatible with the collagen expression by IHC test. The fluorescent PSR imaging method seems to be promising, but it must still be studied in the comparative oncology. Fewer studies with formalin-fixed paraffin-embedded (FFPE) samples of canine tumors were conducted to analyze the collagens fibers by PSR [19, 25, 26]. Bedoya et al., [27] used PSR staining in canine squamous cell carcinomas (SCCs), classified in well and poorly

 doi:10.20944/preprints201901.0082.v2

differentiated. The percentage of Col-I was approximately 30% for low- and high-grade SCCs. Their results showed higher percentage of collagen fibers than observed in our study, comparing normal and canine PC, but these are different tumors, with different patterns and locations.

The interaction between the EMC components and metastatic progression is widely studied in human cancers. However, the literature lack information regarding the collagen fibers and elastin expression in human and canine PC tissues. The previous human literature is focused on the role of EMC components in prostate cancer cells [28, 29], instead human prostatic tissue [30, 31]. The Type I collagen degradation product (ICTP) was previously investigated in human PC, predicting bone metastasis type and activity [30]. However, the ICPT expression is evaluated in serum and these authors did not evaluated the collagen I expression in the prostatic samples. In this study, we evaluated the Coll-I immunoexpression in normal and neoplastic prostates, and did not study metastatic disease, which could be an interesting information.

Coll-I and III gene and protein expression were previously evaluated in human PC, using RT-qPCR and IHC [32]. These authors also correlated Coll-I expression with Gleason score. No correlation was found between protein and gene expression for both collagens. However, the IHC analysis showed that Coll-I and Coll-III was significantly reduced in PC, in all Gleason scores, when compared to benign areas. These authors suggested that collagen reduction in PC could be the result from high metalloproteinase (MMP) activity [32]. The MMPs have been correlated with the tissue invasion and tumor progression of different tumors [33]. In human PC, tissue inhibitors of matrix metalloproteinases (TIMPs) and MMPs dysregulation are caused by a significant gain of MMP-2 and 9 expression and TIMP-1 loss. The increased MMP-2 and 9 expression leads the degradation of collagen fibers being the evaluation of Coll-I expression trick. In canine PC, MMP-2 and MMP-9 were previously evaluated and authors found a protein overexpression, when compared PC to normal prostate. However, the authors did not compare the results with collagen expression [34]. Based on this previous description in canine PC, the MMP-2 and 9 overexpression can induce a collagen degradation interfering the collagen evaluation by IHC and PSR [34].

Comparing the Gleason score and the Coll-I and III immunostaining, we did not find statistical difference. Probably due the low number of cases. On the other hand, we identified a higher Coll-III expression in PC samples compared to normal sample by PSR and IHC. Duarte et al. [32] evaluated Coll-I, Coll-III, MMP2 and MMP9 expression in human prostate cancer by gene and protein expression. These authors found a Coll-III down expression compared to PH. Furthermore, high MMP 9 expression was found, indicating a degradation of Coll-III by MMP9. On the other hand, in human SCC, the Coll-III overexpression was associated with a worst prognosis sand higher tumor grade [35].

The pattern of Col-IV expression in this study was similar to normal human prostate and PC [36]. An interesting finding was that solid canine PC had lower/absent Coll-IV expression than other PC patterns and normal tissues. Sinha et al., [37] found that Coll-IV immunostaining was less uniform or absent in the BM of poorly-differentiated human PC when compared to well-differentiated PC, HBP and normal human prostates. Similar results were also observed in feline and canine mammary tumors as well as in canine hemangiosarcoma [25, 26].

We found a normal pattern [37] of elastic fibers in canine prostate (in the septa dividing the lobules, around the alveoli, ducts and the urethra). The interesting result was thatcanine PC, had a statistical higher median of elastin fibers ($p=0.00229$) than normal tissue. Elastin fibers are involved in tumor invasion and metastasis [38], cell proliferation, adhesion, apoptosis and angiogenesis [39].

The collagen and elastin patterns in the prostate gland are dynamic and important differences can be found in different species. Beside that, the prostate gland anatomy, the animal breed, age and castration status can lead in different collagen and elastin fiber patterns [22]. In this study, we lack information regarding the region of the prostate gland (periurethral, peripheral or of the prostate biopsy) that the tissue specimens were collected. Thus, we strongly recommend the annotation of each region that the prostatic tissue was collected before evaluating the EMC components in canine prostate.

5. Conclusions

The distribution and percentage area of collagen are similar in normal and neoplastic canine prostate, when analyzed with PSR and IHC tests. In addition, the immunohistochemical localization of elastic system fibers is similar in both groups. Only, in canine PC with solid pattern was identified loss of Col-IV compared to others tumor patterns and normal prostate samples.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: Histological type of 10 canine prostatic carcinomas, according to Eble et al., 2004 and Palmieri et al., 2014.

Author Contributions: Conceptualization, L.GV.C., C.E.F.A. and R.L.A.; methodology, L.G.R.C. and P.E.K.; formal analysis, L.G.R.C. and C.E.F.A.; investigation, L.G.R.C. and C.E.F.A.; resources, R.L.A.; data curation, L.G.R.C., C.E.F.A. and R.L.A.; writing—original draft preparation, L.G.R.C.; writing—review and editing, C.E.F.A., P.E.K., R.O.V. and R.L.A.; supervision, R.O.V. and R.L.A.; project administration, C.E.F.A.X.X.; funding acquisition, R.L.A. and C.E.F.A.

Funding: This research was funded by National Council for Scientific and Technological Development - CNPq, grant number 443884/2014-5 and 422139/2018-1.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ferlay, J., Soerjomataram, I., Ervik, M., Dikshit, R., Eser, S., Mathers, C., Rebelo, M., Parkin, D. M., Forman, D., Bray, F. Cancer incidence and mortality worldwide: Source, methods and major patterns in GLOBOCAN 2012. *Int. J.* Cancer. **2014**, *136*. doi: 10.1002/ijc.29210.
2. Mundy, G. Metastasis to bone: causes, consequences and therapeutic opportunities. *Nat. Rev. Cancer*, **2002**, *2*, 584-593. DOI: 10.1038/nrc867.
3. Leroy, B. R., Northrup N. Prostate cancer in dogs: comparative and clinical aspects. Vet. J. **2009**, *180*, 149-162. DOI: 10.1016/j.tvjl.2008.07.012
4. Palmieri, C., Lean, F. Z., Akter, S. H., Romussi, S., Grieco, V. A retrospective analysis of 111 canine prostatic samples: histopathological findings and classification. *Res. Vet. Sci.* **2014** *97*, 568-73. DOI: 10.1016/j.rvsc.2014.11.006
5. Argyle, D. J. Prostate cancer in dogs and men: unique opportunity to study the disease. *Vet. J.* **2009**, *180*, 137-138. DOI: 10.1016/j.tvjl.2008.08.012.
6. Palmieri, C., Grieco, V. (2015). Proposal of Gleason-like grading system of canine prostate carcinoma in veterinary pathology practice. Research and Veterinary Science, 103, 11-15. doi: 10.1016/j.rvsc.2015.09.004.
7. Fonseca-Alves CE, Kobayashi PE, Rivera Calderón LG, Felisbino SL, Rinaldi JC, Drigo SA, Rogatto SR, Laufer-Amorim R. Immunohistochemical panel to characterize canine prostate carcinomas according to aberrant p63 expression. *PLoS One*. **2018**, *12*;13(6):e0199173. DOI: 10.1371/journal.pone.0199173.
8. Palumbo, A. Jr., Ferreira, L. B., Reis de Souza, P. A., Oliveira, F. L., Pontes, B., Viana, N. B., Machado, D. E., Palmero, C. Y.,Alves L. M., Gimba, E. R., Nasciutti, L. E. Extracellular matrix secreted by reactive stroma is a main inducer of pro-tumorigenic features on LNCaP prostate cancer cells. *Cancer Lett.* **2012**, *321*, 55-64. DOI: 10.1016/j.canlet.2012.02.026
9. Penet, M. F., Kakkad, S., Pathak, A. P., Krishnamachary, B., Mironchik, Y., Raman, V., Solaiyappan, M., Bhujwalla, Z. M. Structure and function of prostate cancer dissemination-permissive extracellular matrix. *Clin Cancer Res.* **2016**, *23*, 2245-2254. DOI: 10.1158/1078-0432.CCR-16-1516.
10. Frantz, C. Stewart, K. M., Weaver, V. M. The extracellular matrix at a glance. *J. Cell. Sci.* **2010**, *123*, 4195-4200. DOI: 10.1242/jcs.023820.
11. Theocharis, A. D., Skandalis, S. S., Gialeli, C., Karamanos, N. K. (2016). Extracellular matrix structure. *Adv. Drug Deliv. Rev*, **2016**, *97*, 4-27. DOI: 10.1016/j.addr.2015.11.001.
12. Rozario, T., DeSimone, D. W. (2010). The extracellular matrix in development and morphogenesis: a dynamic view. Developmental Biology, 341, 126-140. doi: 10.1016/j.ydbio.2009.10.026.
13. Tuxhorn, J. A., Ayala, G. E., Rowley, D. R. (2001). Reactive stroma prostate cancer progression. The journal of the urology,166, 2472-2483.
14. Zhang, K., Corsa, C. A., Ponik, S. M., Prior, J. L., Piwnica-Worms, D., Eliceiri, K. W., Keely, P. J., Longmore, G. D. (2013). The collagen receptor discoidin domain receptor 2 stabilizes SNAIL1 to facilitate breast cancer metastasis. Nature cell biology, 15, 677-687. doi: 10.1038/ncb2743.

15. Zeng, Z. S., Cohen, A. M., Guillem, J. G. (1999). Loss of basement membrane type IV collagen is associated with increased expression of metalloproteinases 2 and 9 during human colorectal tumorigenesis. Carcinogenesis, 20, 749-755.
16. Tanjore, H., Kalluri, R. (2006). The role of type IV collagen and basement membranes in cancer progression and metastasis. American Journal of Pathology, 168, 715-717. doi: 10.2353/ajpath.2006.051321.
17. Provenzano, P. P., Inman, D. R., Eliceiri, K. W., Knittel, J. G., Yan, L., Rueden, C. T., White, J. G., Keely, P. J. (2008). Collagen density promotes mammary initiation and progression. BMC Medicine, 28;6:11. doi: 10.1186/1741-7015-6-11.
18. Li, A., Zhou, T., Guo, l., Si, J. (2010). Collagen type I regulates ß-catenin tyrosine phosphorylation and nuclear translocation to promote migration and proliferation of gastric carcinoma cells. Oncology Reports, 23, 1247-1255.
19. Case, A., Brisson, B. K., Durham, A. C., Rosen, S., Monslow, J., Buza, E., Salah, P., Gillem, J., Ruthel, G., Veluvolu, S., Kristiansen, V., Puré, E., Brown, D. C., Sørenmo, K, U., Volk, S. W. (2017). Identification of prognostic collagen signatures and potential therapeutic stromal targets in canine mammary gland carcinoma. PLoS One, 12, e0180448. doi: 10.1371/journal.pone.0180448.
20. Eble, J. N., Sauter, G., Epstein, I. A. SesterhennPathology and genetics of tumours of the urinary system and male genital organs. International Agency for Research on Cancer, Lyon, France, 2004.
21. Coleman, R. (2011). Picrosirius red staining revisited. Acta Histochemica, 113, 231-233. doi: 10.1016/j.acthis.2010.02.002.
22. Ruetten, H., Wegner, K.A., Romero, M.F., Wood, M.W., Marker, P.C., Strand, D., Colopy, S.A., Vezina, C.M. (2018) Prostatic collagen architecture in neutered and intact canines. Prostate. 78(11), 839-848. doi: 10.1002/pros.23641.
23. Bauman, T. M., Nicholson, T. M., Abler, L. L., Eliceiri, K. W., Huang, W., Vezina, CM., Ricke, W. A. (2014). Characterization of fibrillar collagens and extracellular matrix of glandular benign prostatic hyperplasia nodules. PLoS One, 9, e109102. doi: 10.1371/journal.pone.0109102.
24. Wegner, K. A., Keikhosravi, A., Eliceiri, K. W., Venzina C. M. (2017). Fluorescence of picrosirius red multiplexed with immunohistochemistry for the quantitative assessment of collagen in tissue sections. The journal of histochemistry and cytochemistry, 65, 8, 479-490.
25. Benazzi, C., Sarli, G., Galeotti, M., Marcato, P. S. (1993). Basement membrane components in mammary tumours of the dog and cat. Journal of comparative pathology, 109, 3, 241-252.
26. Murakami, M., Sakai, H., Kodama, A., Yanai, T., Mori, T., Maruo, K., Masegi, T. (2009). Activation of matrix metalloproteinase (MMP-2) by membrane type 1-MMP and abnormal immunolocalization of the basement membrane components laminin and type IV collagen in canine spontaneous hemangiosarcomas. Histology and Histopathology, 24, 437-446. doi: 10.14670/HH-24.437.
27. Bedoya, S.A.O., Conceição, L.G., Viloria, M.I.V., Loures, F.H., Valente, F.L., Amorim, R.L., & Silva, F.F. (2016). Caracterização de colágenos tipos I e III no estroma do carcinoma de células escamosas cutâneo em cães. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 68(1), 147-154. https://dx.doi.org/10.1590/1678-4162-8484
28. Koutsilieris, M., Sourla, A., Pelletier, G., Doillon, C.J. (1994) Three-dimensional type I collagen gel system for the study of osteoblastic metastases produced by metastatic prostate cancer. J Bone Miner Res. 9(11), 1823-32.
29. Hall, C.L., Dai, J., van Golen, K.L., Keller, E.T., Long, M.W. Type I collagen receptor (alpha 2 beta 1) signaling promotes the growth of human prostate cancer cells within the bone. Cancer Res. 2006 Sep 1;66(17):8648-54.
30. Kylmälä, T., Tammela, T.L., Risteli, L., Risteli, J., Kontturi, M., Elomaa, I. (1995). Type I collagen degradation product (ICTP) gives information about the nature of bone metastases and has prognostic value in prostate cancer. Br J Cancer., 71(5), 1061-4.
31. Burns-Cox, N., Avery, N.C., Gingell, J.C., Bailey, A.J. (2001). Changes in collagen metabolism in prostate cancer: a host response that may alter progression. J Urol., 166(5), 1698-701.
32. Duarte, A. H., Colli, S., Alves-Pereira, J. L., Martins, M. P., Sampaio, F. J. B., Ramos, C. F. (2012). Collagen I and III metalloproteinase gene and protein expression in prostate câncer in relation to Gleason score. International Braz J Urol, 38, 341-354.
33. Brehmer, B., Biesterfeld, S., Jakse, G. (2003). Expression of matrix metalloproteinases (MMP-2 and -9) and their inhibitors (TIMP-1 and -2) in prostate cancer tissue. Prostate Cancer Prostatic Dis., 6(3), 217-22.

34. Faleiro, M. B., Croce, G. B., Toledo, D. C., Rodrigues, M. M., Batista, A. C., Damasceno, A. D., Brito, L. A., Laufer-Amorim, R., De Moura, V. M. (2013). Matrix metalloproteinases 2 and 9 expression in canine normal prostate and with proliferative disorders. Ciência Rural, 43, 6. doi: 10.1590/S0103-84782013005000050.
35. Kumari, K., Ghosh, S., Patil, S., Augustine, D., Samudrala Venkatesiah, S., Rao, R.S. (2017). Expression of type III collagen correlates with poor prognosis in oral squamous cell carcinoma. J Investig Clin Dent. 2017, 8(4). doi: 10.1111/jicd.12253.
36. Sinha, A. A., Gleason, D. F., DeLeon, O. F., Wilson, M. J., Limas, C., Reddy, P. K., Furcht, L. T. (1991). Localization of type IV collagen in the basement membranes of human prostate and lymph nodes by immunoperoxidase and immunoalkaline phospatase. Prostate, 18, 2, 93-104.
37. Marettová, E. (2017). Immunohistochemical localization of elastic system fibres in the canine prostate. Folia Veterinaria, 6, 1,5-10. doi: 10.1515/fv-2017-0001.
38. Krušlin B, Ulamec M, Tomas D. Prostate cancer stroma: an important factor in cancer growth and progression. Bosn J Basic Med Sci. 2015 May 13;15(2):1-8. doi: 10.17305/bjbms.2015.449.
39. Scandolera A, Odoul L, Salesse S, Guillot A, Blaise S, Kawecki C, Maurice P, El Btaouri H, Romier-Crouzet B, Martiny L, Debelle L, Duca L. The Elastin Receptor Complex: A Unique Matricellular Receptor with High Anti-tumoral Potential. Front Pharmacol. 2016 Mar 4;7:32. doi: 10.3389/fphar.2016.00032.