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## Cancer-associated changes in expression of *TMPRSS2-ERG*, *PCA3* and *SPINK1* in histologically benign tissue from cancerous versus non-cancerous prostatectomy specimens

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### Abstract

**Objective**—To investigate whether mRNA expression of *TMPRSS2-ERG* fusion gene, a suggested prostate cancer (PCa) biomarker, was specific to cancerous lesions alone and to study the expression of *SPINK1* and *PCA3* mRNAs in the same cohort to also explore the proposed mutual exclusivity of *TMPRSS2-ERG* and *SPINK1* expression.

**Methods**—Levels of two *TMPRSS2-ERG* transcripts, *PCA3*, and *SPINK1* mRNAs were measured with highly standardized RT-qPCR assays in cystoprostatectomy specimens from 19 invasive bladder cancer patients and in 174 radical prostatectomy (RP) samples [88 histologically

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#### Conflicts of interest:

Riina-Minna Väänänen: none

Hans Lilja: Dr Lilja holds patents for free PSA, intact PSA and hK2 assays.

Leni Kauko: none

Pauliina Helo: none

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benign prostate (HBP) tissues and 86 from cancerous lesions] from 87 patients with clinically localized PCa.

**Results**—Expression of *TMPRSS2-ERG* transcripts was detected in 45/88 (51%) HBP tissues from RP specimens, and more frequently (57/86, 66%) found in cancerous lesions. By contrast, *TMPRSS2-ERG* expression was detected in only 2/19 (11%) cystoprostatectomy specimens, both with incidental PCa foci elsewhere in the gland. Similar trends of changes in the expression of *PCA3* and *SPINK1* were present in HBP tissue from RP compared to cystoprostatectomy specimens.

**Conclusions**—Although expression of *TMPRSS2-ERG*, *SPINK1*, and *PCA3* mRNA is higher or more frequently found in cancerous lesions, HBP tissues from patients with clinically localized PCa manifest molecular, mRNA level changes that are absent in cystoprostatectomy specimens lacking incidental PCa foci, or infrequent in cystoprostatectomy specimens containing incidental PCa. If this finding is replicated, these molecular assays could be used to inform men with negative biopsies about the likelihood of cancerous lesions in unsampled regions and hence the need for repeat biopsy.

### Keywords

Prostatic Neoplasms; Gene Expression; Reverse Transcriptase Polymerase Chain Reaction; *TMPRSS2-ERG*; *PCA3*; *SPINK1*

## INTRODUCTION

Fusion between genes *TMPRSS2* (transmembrane protease serine 2) and *ERG* (ETV related gene) has been suggested as a novel, cancer-specific marker for prostate cancer (PCa)<sup>1</sup>. With the high prevalence of PCa, it may be the most common cancer-associated genetic rearrangement as studies have shown it to be present in about 40–70% of PCa cases. This gene fusion has been identified in a subset of prostatic tumors with potentially distinct disease characteristics. The details of those characteristics are still debated as contradictory results on different transcript isoforms and their effects on prognosis have been reported<sup>2,3</sup>. The cancer specificity of this gene fusion has been questioned as *TMPRSS2-ERG* expression has been detected also in histologically benign tissue of cancerous prostates<sup>4,5,6</sup>, but cancer-related changes of gene expression in non-neoplastic tissue of cancer-affected prostates are not unheard of and have been reported for other biomarkers as well<sup>7,8,9</sup>.

Another subgroup of PCa was suggested when *SPINK1* mRNA, often studied in conjunction with pancreatic diseases but also overexpressed in PCa<sup>10</sup>, was found to be overexpressed preferentially in cancers lacking *TMPRSS2-ERG* fusion<sup>11,12</sup>. However, a recent study by Leinonen et al contradicts this by showing no signs of their mutually exclusive expression<sup>13</sup>.

As most of the previous *TMPRSS2-ERG* studies have been DNA- and FISH-based, we set out to study the mRNA transcript levels of the fusion gene, targeting two of the over 20 transcript isoforms that have been reported<sup>14</sup>: transcripts III and VI. *TMPRSS2-ERG* III is the most commonly expressed isoform<sup>1</sup> and *TMPRSS2-ERG* VI was chosen for its claimed association with aggressive disease<sup>15</sup>. For this purpose, we developed highly sensitive, truly quantitative and internally standardized reverse-transcription PCR (RT-qPCR) assays for both *TMPRSS2-ERG* transcript isoforms as well as for *SPINK1* mRNA, employing a previously described assay concept<sup>16</sup>. The mRNA levels of these three markers were measured in 86 cancerous prostate tissues and 88 histologically benign prostate tissues (HBP) from 87 PCa patients, and in prostatic tissue specimens obtained by cystoprostatectomy from 19 patients with invasive cancer of the urinary bladder and with no history of PCa. In addition to measuring the absolute levels of expression with a truly

quantitative method, our aim was to find out whether the previously reported<sup>4,5,6</sup>, occasional presence of the gene fusion in benign tissue in men with PCa was evidence of a field effect or due to the gene fusion not being truly cancer specific. We also sought to explore the claimed mutual exclusivity between *SPINK1* and *TMPRSS2-ERG* fusion gene and whether there were alterations in their expression levels correlating to the neoplastic characteristics of the tissue. Association with PCa stage and tumor percentage was also assessed for all transcripts.

Our previously reported data on higher-than-expected levels of *PCA3* in HBP tissue of cancer-affected prostates compared to cancerous tissues<sup>17</sup> raised questions on the field effect hypothesis regarding that gene. Those issues were also explored further in this study by measuring the mRNA levels of *PCA3* in the 19 cystoprostatectomy specimens and by comparing those levels to the previously obtained values of *PCA3* expression in HBP and cancerous tissue of these 87 PCa patients.

## MATERIALS AND METHODS

### Tissue samples

We obtained 174 prostate tissue samples from 87 PCa patients immediately after radical prostatectomy (RP) at Turku University Hospital, Turku, Finland. Two small sample wedges were taken from each prostate, one intending to sample the suspected cancer area and the other the control area. A small tissue sample size ensured the best possible homogeneity of material. Based on the histological examination of the immediately adjacent tissue surrounding each sampling site, an experienced senior genitourinary pathologist classified 76 samples as histologically benign tissue, 12 as prostatic intraepithelial neoplasia (PIN), and 86 as cancerous tissue ranging from Gleason grade 2 to 5. The PIN samples were considered as histologically benign tissue in all subsequent analyses unless stated otherwise. The estimated median proportion of cancerous tissue in cancerous samples was 30% (interquartile range: 10, 55). Patient characteristics are shown in Supplemental Table 1 and described previously<sup>17</sup>. None of the patients received prior radiation therapy. Samples were stored as previously described<sup>18</sup>.

We also obtained prostate tissue samples from 19 patients undergoing cystoprostatectomy for treatment of invasive bladder cancer at Skåne University Hospital, Malmö, Sweden. Samples were obtained from the peripheral apical or dorsolateral portion of the prostate within 15 minutes after surgical removal and stored deep-frozen. Incidental, small foci of prostate adenocarcinomas were found upon further histopathological assessment in 12/19 of the cystoprostatectomy specimens but not anywhere close to the areas sampled for RNA isolation. Seven cystoprostatectomy specimens contained no evidence of incidental PCa in the prostate.

The study protocol was approved by local Ethics committees and it was in accordance with the Helsinki Declaration of 1975, as revised in 1996, with written informed consent obtained from each participant.

### RNA extraction and reverse transcription

All tissue samples were processed as previously described<sup>18</sup>. RNA extraction protocol included the addition of a known amount of artificial RNA<sup>19</sup> to the samples to act as an internal control, tracking the inherent loss of RNA material throughout the process.

## Real-time qPCR

Expression levels of *SPINK1* and *PCA3* mRNAs and *TMPRSS2-ERG* fusion transcripts types III and VI were measured with optimized RT-qPCR assays using target-specific oligonucleotide probes and time-resolved fluorometry in detection as described previously<sup>18</sup> and in Supplemental Tables 2, 3, and 4. *KLK3* mRNA levels were also determined with an RT-qPCR assay with the same concept<sup>16,21,22</sup> to ensure the presence of prostate cells. Data analysis is described in detail in Supplemental Data 1.

## RESULTS

### KLK3

There were no significant differences in *KLK3* mRNA levels when we compared the expression in cancerous versus HBP tissue from RP specimens ( $p=0.2$ ) from men with clinically localized PCa as previously reported<sup>17</sup>. However, *KLK3* expression tended to be higher in HBP tissue from RP compared to cystoprostatectomy specimens ( $p=0.032$ ).

### TMPRSS2-ERG

Overall, there was evidence of *TMPRSS2-ERG* III expression in 55/87 (63%) and *TMPRSS2-ERG* VI expression in 51/87 (59%) men with clinically localized PCa. Individual tissue samples contained either both of the fusion transcript types, only one of them or neither. Both transcripts were detected in 43/87 (49%) patients, with at least one of the fusion transcripts detected in 63/87 (72%) of these patients.

Of the 88 HBP tissue samples from RP specimens from men with clinically localized PCa, more than half (45/88 or 51%) showed expression of at least one of the *TMPRSS2-ERG* transcripts (Table 1). Expression of either or both of the *TMPRSS2-ERG* transcripts was detected in 57/86 (66%) cancerous tissue samples from the RP specimens. By contrast, *TMPRSS2-ERG* expression was not detected in prostatic tissue from 17 patients with invasive bladder cancer treated with cystoprostatectomy, whereas it was detectable in prostate tissue from two cystoprostatectomy specimens which contained foci of incidental PCa elsewhere in the gland.

Trends of field effect were observed particularly in the paired samples. Of the 48 men from whom both a cancerous and benign sample were obtained, 30 manifested either or both of the *TMPRSS2-ERG* transcripts in the cancerous sample and 21/30 (70%) of them had detectable *TMPRSS2-ERG* transcripts also in the matched HBP tissue. In addition, evidence of multi-clonality was implicated in glands presenting with two cancerous samples. Of the 19 men from whom two cancerous RP samples were obtained, 2 manifested only *TMPRSS2-ERG* III mRNA in one of the samples and only *TMPRSS2-ERG* VI mRNA in the other. Concordance of expression of the two *TMPRSS2-ERG* transcripts between the paired samples is described in full detail in Supplemental Tables 5 and 6.

Both *TMPRSS2-ERG* fusion transcripts were statistically significantly more frequently detected in cancerous than in HBP tissue of the RP specimens from men with clinically localized PCa (for *TMPRSS2-ERG* III,  $p=0.022$  and for *TMPRSS2-ERG* VI,  $p=0.026$ ). Also the differences in the presence of fusion transcripts between HBP tissue from prostates with clinically localized PCa and cystoprostatectomy specimens were statistically significant for both fusion transcripts ( $p=0.020$  for *TMPRSS2-ERG* III and  $p=0.033$  for *TMPRSS2-ERG* VI). There was no statistically significant difference in *TMPRSS2-ERG* III and VI levels between PIN samples and HBP tissue from RP specimens ( $p=0.2$  and 0.11 respectively).

Among the fusion transcript positive samples of the RP specimens from clinically localized PCa, the expression levels of each isoform varied over 5–6 orders of magnitude with no statistically significant difference of mRNA levels between the cancerous and histologically benign groups (Figure 1). The *TMPRSS2-ERG* VI expression levels of the two cystoprostatectomy samples in which the expression of this mRNA was detectable, were  $3.5 \times 10^4$  and  $4.6 \times 10^5$  mRNA copies per  $\mu\text{g}$  of total RNA. The latter sample also presented *TMPRSS2-ERG* III mRNA expression on the level of  $3.2 \times 10^3$  mRNA copies per  $\mu\text{g}$  of total RNA.

Within the samples where *TMPRSS2-ERG* VI mRNA was detectable, isoform VI levels were statistically significantly higher if the same sample also showed detectable III isoform expression (Figure 2). This phenomenon was seen both in cancerous ( $p=0.004$  by Mann-Whitney) and HBP samples ( $p=0.001$ ). However, no statistically significant difference ( $p=0.18$ ) was observed in *TMPRSS2-ERG* III levels regarding whether the samples also expressed *TMPRSS2-ERG* VI or not (Figure 2).

*TMPRSS2-ERG* expression did not associate with Gleason grade of the tissue sample ( $p=0.5$  for both III and VI) but advanced pathologic stage was positively associated with the presence of *TMPRSS2-ERG* III ( $p=0.003$ ), and *TMPRSS2-ERG* VI mRNAs ( $p=0.020$ ) (Supplemental Table 7). There was no significant association between *TMPRSS2-ERG* III and VI mRNA levels and the cancer cell percentage of the tissue samples ( $p=0.8$  and  $p=0.7$ , respectively).

## SPINK1

All samples except one cystoprostatectomy sample contained measurable *SPINK1* mRNA (Figure 3). The cancerous tissue from RP specimens had significantly higher mRNA levels (2.9-fold difference in medians,  $p=0.047$ ) than the HBP tissue of RP specimens from men with clinically localized PCa. Furthermore, *SPINK1* mRNA levels were statistically significantly lower in the cystoprostatectomy samples than in the HBP samples from RP specimens (3.4-fold difference in medians,  $p=0.010$  after adjusting for clustering). The difference in median expression between cancerous tissue of RP specimens and cystoprostatectomy samples was 10-fold ( $p<0.001$ ).

Neither Gleason grade of the tissue sample ( $p=0.4$ ) nor advanced pathologic stage ( $p=0.3$ ) was significantly associated with *SPINK1* mRNA expression levels (Supplemental Table 7). There was no significant association between *SPINK1* mRNA levels and the cancer cell percentage of the tissue samples ( $p=0.3$ ).

The presence of *TMPRSS2-ERG* transcripts did not correlate with *SPINK1* levels ( $p=0.8$  for *TMPRSS2-ERG* III and  $p=0.6$  for *TMPRSS2-ERG* VI), but there was a statistically significant association between *SPINK1* mRNA levels and *TMPRSS2-ERG* III and VI levels ( $p=0.001$  and  $p=0.041$ , respectively) in those samples where *TMPRSS2-ERG* fusion transcripts were detected.

## PCA3

*PCA3* mRNA was detectable in all 19 cystoprostatectomy samples. The median *PCA3* mRNA level in those samples was  $7.9 \times 10^4$  mRNA copies per  $\mu\text{g}$  of total RNA, which is 613-fold lower than the previously reported median *PCA3* expression level in cancerous tissues<sup>17</sup> and 107-fold lower than the previously reported median<sup>17</sup> in HBP tissue of cancer-affected prostates. These differences were statistically significant ( $p<0.0001$ ), but there was no statistically significant difference between *PCA3* mRNA levels in cystoprostatectomy



samples from cancer-free prostates (n=7) and levels in samples from prostates with incidental cancer foci elsewhere in the prostate (n=12) (p=0.18).

## DISCUSSION

Although a significantly higher frequency of *TMPRSS2-ERG* transcripts was found in the cancerous tissue compared to the HBP tissue from the prostates harboring clinically localized cancer, the frequency of *TMPRSS2-ERG* expression remained high in samples from histologically benign areas. In contrast, fusion gene transcripts were detectable only rarely in cystoprostatectomy samples from bladder cancer patients and never without concomitant incidental tumor foci present in the same prostate. Thus *TMPRSS2-ERG* expression can be detected in histologically normal prostate tissue obtained from a prostate in which tumors were detected. A similar trend was seen in *PCA3* and *SPINK1* mRNA levels.

The presence of *TMPRSS2-ERG* fusions has been widely considered to be a cancer-specific event<sup>1</sup>, but we detected *TMPRSS2-ERG* III and/or VI mRNAs also in 51% of HBP tissues of RP specimens from prostates with clinically localized PCa (compared to 66% in the cancerous RP samples). The phenomenon of *TMPRSS2-ERG* positive, benign-appearing prostate tissue has been reported before on a few occasions<sup>4,5,6</sup>. In previous studies, it has mainly been considered an anomaly, but a conceivable explanation could be a carcinogenic field effect<sup>23</sup>, which suggests that a larger area than just the tumor focus is originally changed in terms of neoplastic events due to a carcinogenic signal that has affected the entire area<sup>24</sup>. This type of area can appear histologically normal, albeit molecular changes may still be detectable. Field effect-related observations in PCa<sup>8,9,25,26</sup> led us to the hypothesis that the HBP tissue of PCa patients in this study may have undergone molecular changes with regard to *PCA3* and *SPINK1* genes and *TMPRSS2-ERG* fusion events even though the histological examination defined the samples as non-neoplastic. This is further supported not only by the fact that the two cystoprostatectomy samples that presented *TMPRSS2-ERG* expression, were taken from prostates that in pathologic sectioning studies were found to contain incidental prostate tumor foci, but also by the higher likelihood of the HBP samples to contain detectable *TMPRSS2-ERG* mRNA if the matched cancerous sample was also *TMPRSS2-ERG* fusion-positive.

The previously reported ranges of 10–100-fold overexpression of *PCA3* in cancerous tissue<sup>27,28</sup> did not seem to be in line with our recent results where the control tissue was HBP tissue from prostates with clinical PCa and only a 5.7-fold overexpression was observed<sup>17</sup>. However, in light of this study where we determined the *PCA3* expression in benign prostate tissue from cystoprostatectomy specimens and compared it with the previously measured levels of *PCA3* mRNA in tissue of cancer-affected prostates, the overexpression of *PCA3* is more pronounced when the cancerous tissue is, in fact, compared to tissue from prostates without clinical PCa. The cohort of prostates without clinical PCa is admittedly limited in this study, but nevertheless, this suggests that the *PCA3* levels may also be elevated in histologically benign areas of the cancerous prostate when compared to cancer-free prostates – as was seen here as a 107-fold difference in mRNA levels.

*SPINK1* has been claimed to be overexpressed in PCa<sup>9,29</sup> and also to exclusively identify a subgroup of PCas lacking *TMPRSS2-ERG* fusion, although contradictory results have been reported as well<sup>13</sup>. In this study, we did not find them to be mutually exclusive, but did observe a positive correlation between *SPINK1* and *TMPRSS2-ERG* mRNA levels in the samples where *TMPRSS2-ERG* fusion transcripts were detected. However, measuring transcripts in tissue extracts does not allow a specific detection of different transcripts in the individual tumor cells which is a limitation with our and previous studies. A possible co-

expression of gene fusions and *SPINK1* mRNA in the same tumor cells still needs to be clarified.

Despite the small size of the studied cohort, these findings reported here suggest that detection of *TMPRSS2-ERG* fusion transcripts is indicative of presence of prostatic tumor in the corresponding prostate, whether or not the sampled cells appear neoplastic in histological examinations. As it was possible to examine histologically only the immediately adjacent tissue, and not the actual tissue used for the RT-qPCR analyses, we cannot exclude the possibility that cancer cells may have resided in the tissue deemed benign using established state-of-art histopathological analyses. It however seems unlikely that this would be the case for such a large number of samples used in our study. However, this study does not reveal whether the finding of *TMPRSS2-ERG* transcripts can be made even before the emergence of the tumor. If the expression of fusion transcripts is considered an early event, it may, as an inducing carcinogenic signal, be present also before the formation of histologically evident tumor foci. This could therefore give very early information not only about the likelihood of already established disease but also about increased future risk of tumor formation in the prostate even in cases where no tumor tissue was found by the biopsy procedure. Using RT-qPCR assays for determining the molecular composition of biopsy material could conceivably constitute an informative adjunct to the traditional histological examination, and this creates an interesting option calling for future studies. Extraction of nucleic acids from prostate biopsy material is technologically feasible<sup>30</sup> although the amount of tissue used to extract nucleic acids would compete with the amount used for histopathological evaluation.

## CONCLUSIONS

To conclude, histologically benign tissue from a prostate affected by PCa can present molecular level changes in mRNA expression regarding the fusion gene *TMPRSS2-ERG* and *PCA3* and *SPINK1* genes. Thus, molecular tools such as the markers studied here could provide a means to identify an enhanced risk of PCa or presence of already established PCa missed by the biopsy procedure.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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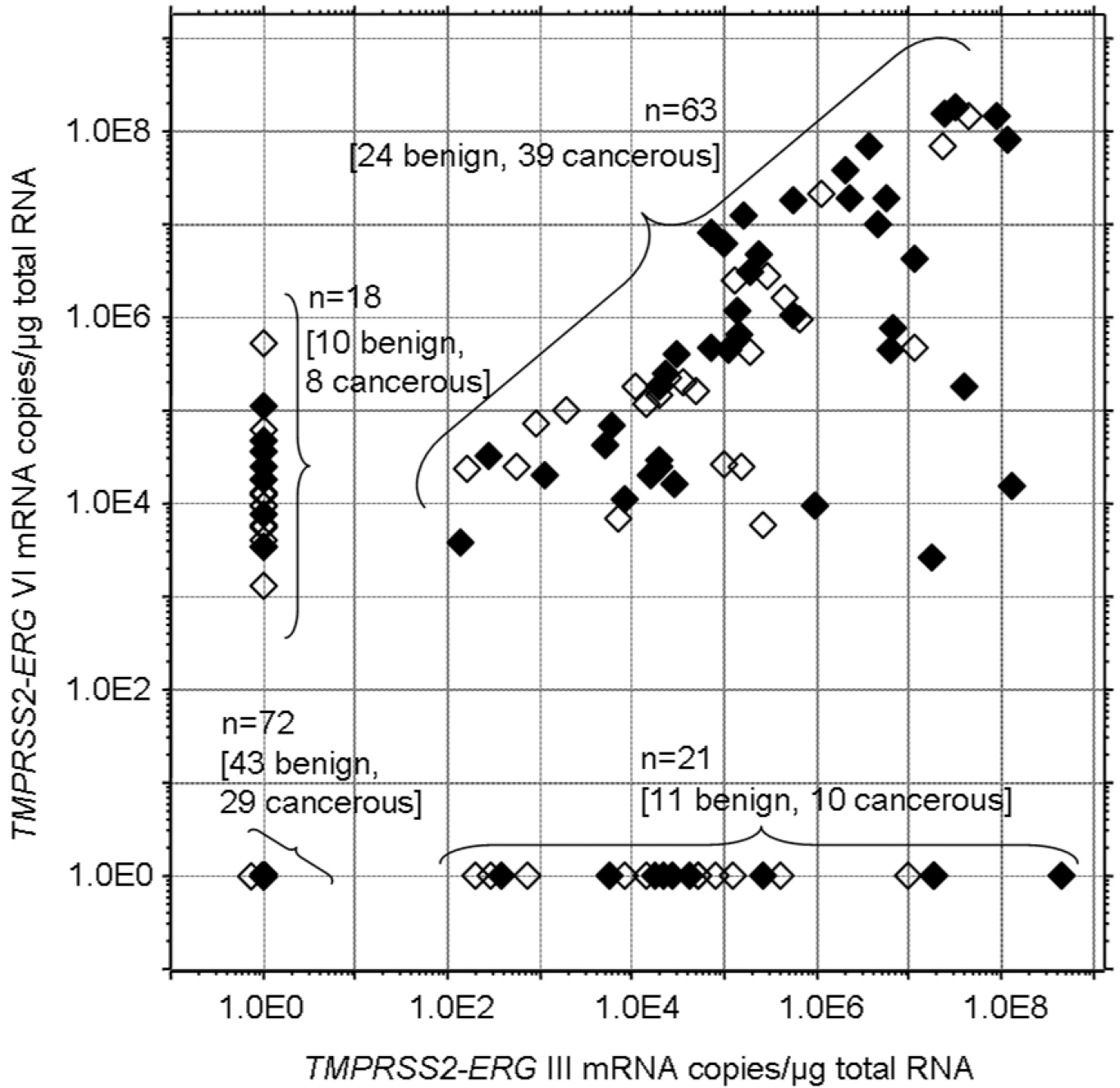
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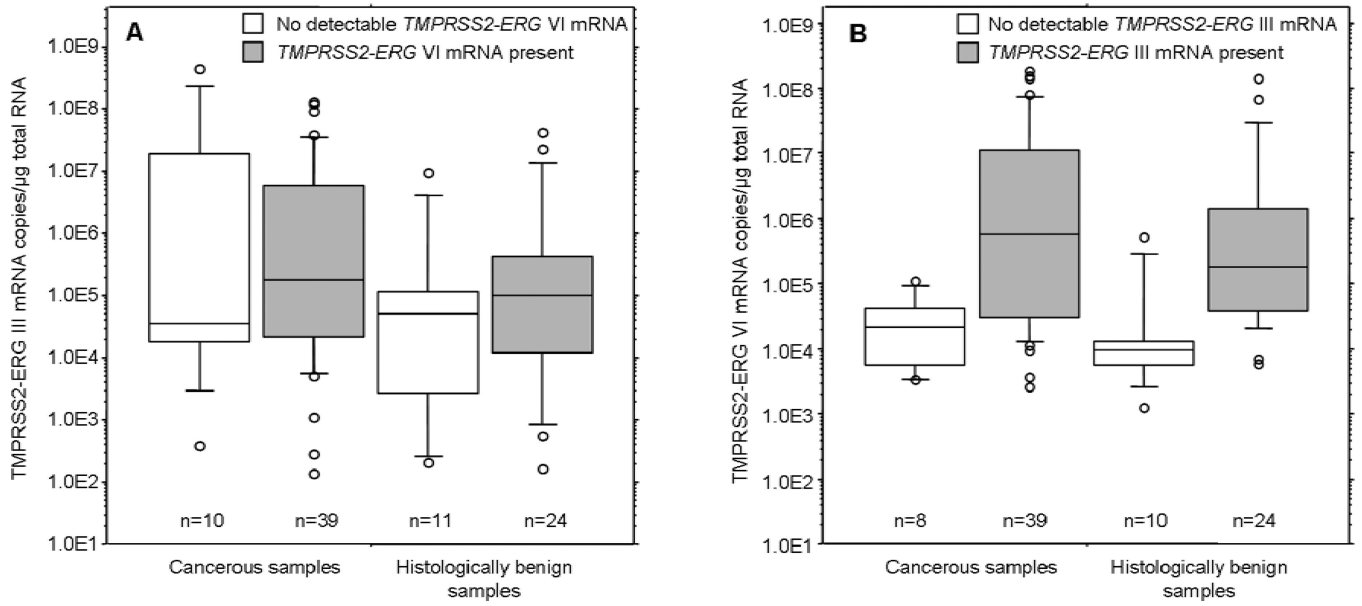
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**Figure 1.** *TMPRSS2-ERG* III and VI mRNA levels in 174 radical prostatectomy samples. The open diamonds denote histologically benign tissue samples and the closed diamonds represent cancerous sample. When mRNA was not detected, the sample was given the value 1.

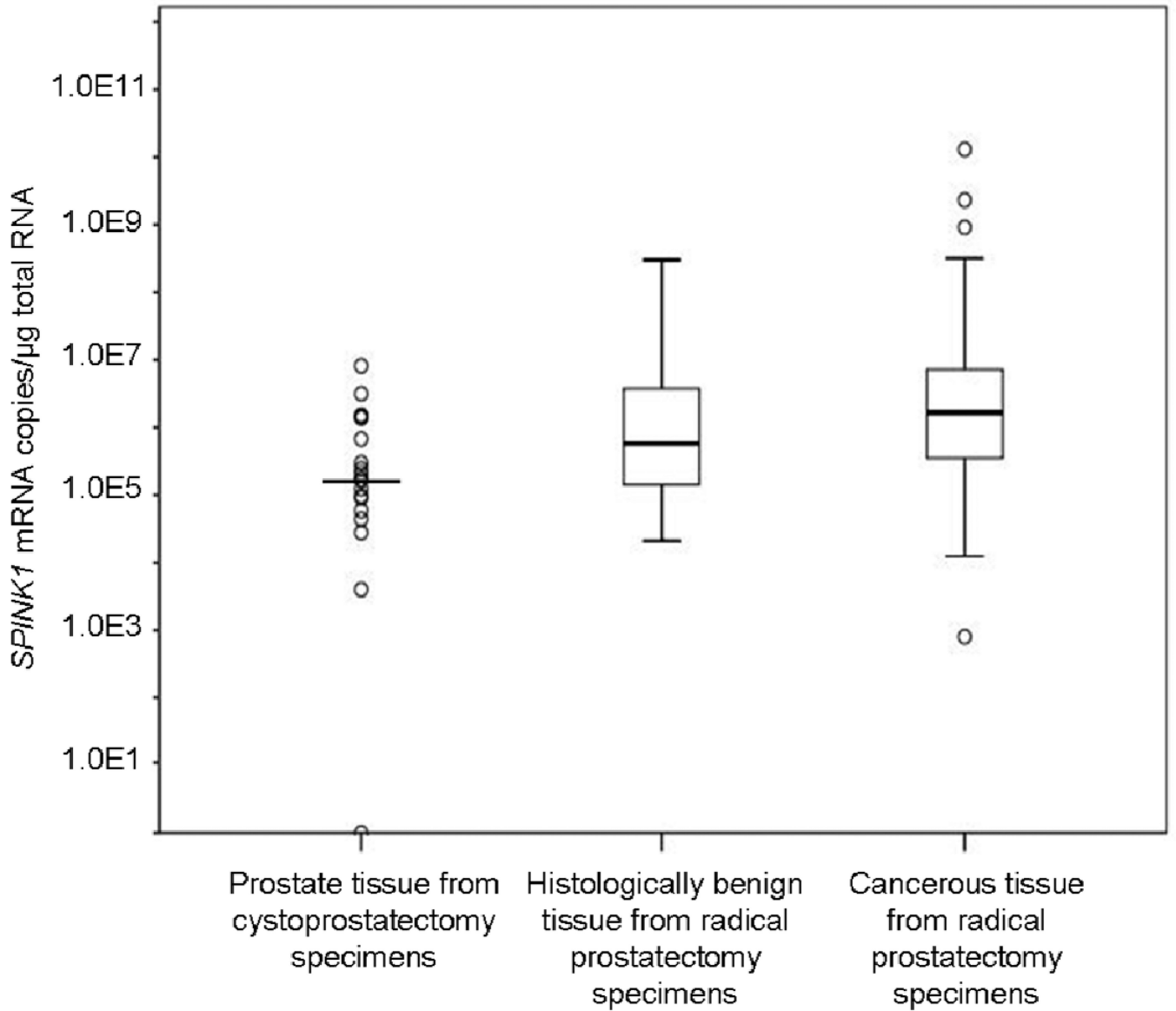


**Figure 2.**

A. *TMPRSS2-ERG III* mRNA levels in cancerous and histologically benign samples with (grey) or without (white) detectable *TMPRSS2-ERG VI* mRNA expression.

B. *TMPRSS2-ERG VI* mRNA levels in cancerous and histologically benign samples with (grey) or without (white) detectable *TMPRSS2-ERG III* mRNA expression.

The 10/25/50/75/90<sup>th</sup> percentiles are marked in the figures and open circles denote the outlier values.



**Figure 3.** *SPINK1* mRNA levels in cystoprostatectomy specimens and histologically benign or cancerous areas from radical prostatectomy specimens. For the cystoprostatectomy group, the horizontal line denotes the median value and the open circles denote *SPINK1* mRNA values in individual samples. For the other two groups the 10/25/50/75/90<sup>th</sup> percentiles are marked in the figure and open circles denote the outlier values.

**Table 1**

Frequencies of *TMPRSS2-ERG* III and VI mRNA expression detected in histologically benign tissues of prostates with clinical PCa, PIN tissue, cancerous prostate tissues and in tissues of clinical PCa-free prostates. PIN, prostatic intraepithelial neoplasia; RP, radical prostatectomy.

	Number of samples				Total
	Only <i>TMPRSS2-ERG</i> III mRNA was detected	Only <i>TMPRSS2-ERG</i> VI mRNA was detected	Both <i>TMPRSS2-ERG</i> III and VI mRNAs were detected	Neither <i>TMPRSS2-ERG</i> III nor VI mRNA were detected	
Histologically benign tissue from RP specimens (including the 12 PIN samples)	11 (13%)	10 (11%)	24 (27%)	43 (49%)	88
PIN tissue from RP specimens	0 (0%)	4 (33%)	3 (25%)	5 (42%)	12
Cancerous prostate tissue from RP specimens	10 (12%)	8 (9%)	39 (45%)	29 (34%)	86
Prostate tissue from cystoprostatectomy specimens	0 (0%)	1 (5%)	1 (5%)	17 (89%)	19