[CANCER RESEARCH 62, 295–300, January 1, 2002]

Human Kallikrein 11: A New Biomarker of Prostate and Ovarian Carcinoma

Eleftherios P. Diamandis,[1] Akira Okui, Shinichii Mitsui, Liu-Ying Luo, Antoninus Soosaipillai, Linda Grass, Terukazu Nakamura, David J. C. Howarth, and Nozomi Yamaguchi

Department of Pathology and Laboratory Medicine, Mount Sinai Hospital, Toronto, Ontario, M5G 1X5 Canada [E. P. D., L-Y. L., A. S., L. G., T. N., D. J. C. H.]; Department of Laboratory Medicine and Pathobiology, University of Toronto, Ontario, M5G 1L5 Canada [E. P. D., L-Y. L., D. J. C. H.]; and Department of Cell Biology, Research Institute for Geriatrics, Kyoto Prefectural University of Medicine, Kyoto 602-8566, Japan [A. O., S. M., N. Y.]

ABSTRACT

Human kallikrein 11 (hK11) is a putative serine protease of the human kallikrein gene family. Currently, no methods are available for measuring hK11 in biological fluids and tissues. Our aim was to develop immunological reagents and assays for measuring hK11 and examine if the concentration of this kallikrein is altered in disease states. We produced recombinant hK11 protein in a baculovirus system and used it to develop monoclonal and polyclonal antibodies against hK11. We then developed an immunofluorometric procedure for measuring hK11 in biological fluids and tissue extracts with high sensitivity and specificity. We further quantified hK11 in various biological fluids and in serum of patients with various cancers. The hK11 immunofluorometric assay is highly sensitive (detection limit, 0.1 μg/l) and specific (no detectable cross-reactivity for other homologous kallikreins). We established the tissue expression pattern of hK11 at the protein level and found the highest levels in the prostate, followed by stomach, trachea, skin, and colon. We have immunohistochemically localized hK11 in epithelial cells of various organs. We further detected hK11 in amniotic fluid, milk of lactating women, cerebrospinal fluid, follicular fluid, and breast cancer cytosols. However, highest levels were seen in prostatic tissue extracts and seminal plasma. hK11 in seminal plasma and prostatic extracts is present at ~300-fold lower levels than prostate-specific antigen and at approximately the same levels as hK2. hK11 expression in breast cancer cell lines is up-regulated by estradiol. Elevated serum levels of hK11 were found in 70% of women with ovarian cancer and in 60% of men with prostate cancer. This is the first reported immunological assay for hK11. Analysis of this biomarker in serum may aid in the diagnosis and monitoring of ovarian and prostatic carcinoma.

INTRODUCTION

PSA[2] is the best described cancer marker and is currently used widely for diagnosis and monitoring of prostatic carcinoma (1). PSA is a member of the hK family of serine proteases and has chymotrypsin-like enzymatic activity. Another member of the hK family, glandular hK2 is a new potential prostatic biomarker (2). Recently, the hK gene family has been expanded to include 15 members that share significant similarities at both the DNA and amino acid level (3, 4). All members of the hK gene family localize on chromosome 19q13.4 and encode for secreted serine proteases. Recently, it has been reported that two members of this family, hK6 and hK10, are potential biomarkers for diagnosis and monitoring of ovarian cancer (5, 6). In addition, many other members of the same family have been found to be overexpressed or underexpressed in ovarian and other cancers (7–16).

The gene encoding hK11 was first cloned by Yoshida *et al.* (17) and was named trypsin-like serine protease. With the newly established kallikrein gene nomenclature, this gene is now known as *KLK11* (the protein is designated as hK11; Ref. 18). Although it has been predicted that this gene will encode for a secreted serine protease, no methods currently exist for measuring hK11 protein in tissue extracts or biological fluids. By reverse transcription-PCR, it was demonstrated that the *KLK11* gene is expressed in many tissues, including brain, skin, salivary gland, stomach, prostate, and intestine (19).

To investigate the potential utility of hK11 analysis in various human diseases, we produced recombinant hK11 protein in a baculovirus system and used it as an immunogen to produce monoclonal and polyclonal antibodies. By using these antibodies, we have constructed the first highly sensitive immunofluorometric assay for hK11 and used it to measure hK11 in tissue extracts, body fluids, and serum. We here show preliminarily, for the first time, that hK11 concentration is elevated in the serum of a subset of patients with prostate and ovarian cancer.

MATERIALS AND METHODS

Recombinant hK11 protein was produced by using a baculovirus system. Briefly, a cDNA fragment encoding the putative mature human hK11 enzyme was fused with trypsinogen signal peptide, followed by histidine hexamer. The chimeric cDNA was inserted into pFastBAC1 vector (Life Technologies, Inc.) and was expressed in insect cells using a Bac-To-Bac baculovirus expression system (Life Technologies, Inc.). The recombinant protein with a histidine tag is secreted into the conditioned medium in this system and can be activated by removing the histidine hexamer with enterokinase. After 35 days infection with the baculovirus expressing the recombinant protein, the conditioned medium was recovered, adjusted to pH 8.0 with 1 M NaOH, and centrifuged at 10,000 $\times$ *g* for 10 min. The supernatant was incubated with 1 ml of chelating resin (Qiagen, Inc., Chatsworth, CA) in base buffer [10 mM Tris-Cl (pH 8.0), 100 mM NaCl] for 3 h at room temperature. The suspended resin was transferred to an open column and washed with 10 mM immidazole in base buffer. The recombinant hK11 was eluted with base buffer containing 50 mM immidazole. Then, the eluant was diluted with 10 mM Tris (pH 8.0), containing 100 mM NaCl and 10 mM $CaCl_2$, was applied to a Con A column (Pharmacia Amersham Biotech), and hK11 was eluted with α-methyl-mannoside. The eluant was digested with recombinant enterokinase (EK Max; Invitrogen) after a buffer change with PD-10 column to 20 mM Tris (pH 7.4) and applied to a Mono Q anion exchange column. The pass through fractions were applied to the MonoS column directly and eluted by stepwise increase of NaCl concentration. hK11 was eluted at the fractions of NaCl concentration around 0.25 M. The protein concentration of the purified recombinant hK11 was determined by the bicinchoninic acid method with BSA as a calibrator (Pierce Chemical Co.). Positive identification and characterization of the recombinant hK11 protein was achieved by using trypsin digestion and nanoelectrospray mass spectrometry, as described previously (20).

Production of Polyclonal and Monoclonal Antibodies against hK11. The purified recombinant hK11 protein was used to immunize rabbits and mice. hK11 (100 μg) was injected s.c. into female BALB/c mice and New Zealand White rabbits. The protein was diluted in complete Freund's adjuvant for the first injection and in incomplete Freund's adjuvant for subsequent injections. Injections were repeated six times at 3-week intervals for the rabbits and three times for the mice. Blood was drawn from the animals and tested for antibody generation. Our screening strategies were similar to those described elsewhere for hK10 (20). The rabbit polyclonal antibodies were used for developing the immunofluorometric assay without further purification.

Monoclonal antibodies against hK11 were produced by using standard hybridoma technology, as described by Campbell 21. Positive clones were identified by screening tissue culture supernatants, as described (20). The

Received 8/7/01; accepted 10/31/01.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked *advertisement* in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

[1] To whom requests for reprints should be addressed, at Department of Pathology and Laboratory Medicine, Mount Sinai Hospital, 600 University Avenue, Toronto, Ontario, M5G 1X5 Canada. E-mail: ediamandis@mtsinai.on.ca.

[2] The abbreviations used are: PSA, prostate-specific antigen; hK, human kallikrein.

positive clones were expanded sequentially in 24-well plates and 6-well plates. Supernatants were further characterized by performing IgG isotyping, and clones were subjected to limiting dilutions. The clones were then expanded in flasks to generate large amounts of supernatants in serum-free medium. The monoclonal antibodies were purified from the supernatants by using protein G-affinity chromatography.

Immunofluorometric Assay for hK11. In the standard assay procedure, one purified anti-hK11 monoclonal antibody diluted in coating buffer (containing 50 mM Tris, pH 7.80) was dispensed into a 96-well white polystyrene microtiter plate (100 μl/500 ng/well) and incubated overnight at room temperature. The plates were then washed three times with washing buffer (containing 9 g/l NaCl and 0.5 g/l Tween 20 in 10 mM Tris-buffer, pH 7.8). One hundred μl of hK11 calibrators (recombinant hK11 in 60 g/l BSA) or samples were applied into each well along with 50 μl of assay buffer. The assay buffer was a 50 mM Tris-buffer (pH 7.80), containing per liter 60 g of BSA, 0.5 mol of KCl, 0.5 g of Tween 20, 10 g of bovine immunoglobulins, 100 ml of goat serum, and 25 ml of mouse serum. The plates were incubated for 2 h on an orbital shaker to allow for hK11 molecules to bind to the plates. The plates were then washed six times. Subsequently, the plates were incubated for 1 h with 100 μl/well of a rabbit anti-hK11 polyclonal antiserum (unpurified), diluted 2000-fold in assay buffer. The plates were then washed six times with washing buffer. One hundred μl of alkaline phosphatase-conjugated goat antirabbit antibody (Jackson Immuno Research), diluted 3000-fold in assay buffer, were added to each well, incubated for 30 min, and washed six times, as described above. Finally, 100 μl of 1 mM diflunisal phosphate, diluted in substrate buffer [0.1 M Tris (pH 9.1), 0.1 M NaCl, and 1 mM $MgCl_2$] were added into each well and incubated for 10 min. One hundred μl of developing solution (1 M Tris-base, 0.4 M sodium hydroxide, 2 mM $TbCl_3$, and 3 mM EDTA) were pipetted into each well and mixed for 1 min. The fluorescence was measured with a time-resolved fluorometer on the CyberFluor 615 Immunoanalyzer (MDS Nordion, Kanata, Ontario, Canada), as described previously (22). The calibration and data reduction was performed automatically.

Determination of Assay Characteristics. The assay characteristics were determined essentially as described elsewhere (20).

Human Tissue Cytosolic Extracts and Biological Fluids. Human tissue cytosolic extracts were prepared as follows. Various frozen human tissues (0.2 g) were pulverized on dry ice to fine powders. Extraction buffer [1 ml, containing 50 mM Tris (pH 8.0), 150 mM NaCl, 5 mM EDTA, 10 g/l NP40 surfactant, 1 mM phenylmethylsulfonyl fluoride, 1 g/l aprotinin, and 1 g/l leupeptin] was added to the tissue powders, and the mixture was incubated on ice for 30 min with repeated shaking and mixing every 10 min. Mixtures were then centrifuged at 14,000 rpm at 4°C for 30 min. The supernatants (cytosolic extracts) were then collected. The biological fluids tested were leftovers of clinical samples submitted for routine biochemical testing at Mount Sinai Hospital. All tissue cytosolic extracts and biological fluids were stored at −80°C until use.

Recovery. Recombinant hK11 was added to human serum samples at different concentrations and measured with the developed hK11 immunoassay. Recoveries were then calculated after subtraction of the endogenous concentrations.

Fractionation of Biological Fluids with Size-Exclusion high-performance liquid chromatography. Biological fluids were fractionated on a silica-based gel filtration column essentially as described elsewhere (20). The fractions were collected and analyzed for hK11 with the developed immunoassay.

Immunohistochemistry. A mouse monoclonal antibody was raised against hK11 full-size recombinant protein produced in yeast cells, as described above. Immunohistochemical staining for hK11 was performed according to a standard immunoperoxidase method. Briefly, paraffin-embedded tissue sections (4 μm) were fixed and dewaxed. Endogenous peroxidase activity was blocked with 3% aqueous hydrogen peroxide for 15 min. Sections were then treated with 0.4% pepsin at pH 2.0 for 5 min at 42°C and blocked with 20% protein blocker (Signet Labs) for 10 min. The primary antibody was then added at 1:3000 dilution for 1 h at room temperature. After washing, biotinylated anti-mouse antibody (Signet Labs) was added, diluted 4-fold in antibody dilution buffer (Dako). After incubation and washing, streptavidin-tagged horseradish peroxidase was added for 30 min at room temperature. After washing, detection was achieved with amino ethyl carbazol for 5–10 min. The slides were then counterstained with hematoxylin and then mounted with coverslips.

Hormonal Regulation of hK11. To study the hormonal regulation of hK11, various cell lines were cultured and then stimulated with different steroids, essentially as described elsewhere (23). All steroid hormones were used at the final concentration of 10^{-8} M. Tissue culture supernatants were collected after 7 days and used for analysis of hK11; PSA was used as a control. PSA analysis was performed with the method described elsewhere (24).

RESULTS

We were able to produce recombinant hK11 protein in baculovirus, bacterial, and yeast expression systems (data not shown). The protein was purified using successive cycles of ion-exchange, affinity, and reverse-phase liquid chromatography, as described previously (20). The identity of the protein was verified by nanoelectrospray mass spectrometry (20). The concentration of the highly purified protein (>99% by SDS-PAGE) was established by the bicinchoninic acid total protein method, with BSA as a standard.

We raised monoclonal mouse antibodies and polyclonal rabbit antibodies using standard techniques (21). One monoclonal antibody was used for coating microtiter plates (capture antibody), and the polyclonal rabbit antibody was used for detection in an ELISA-type sandwich assay. A secondary goat antirabbit polyclonal antibody, labeled with alkaline phosphatase, was also used, and the activity of alkaline phosphatase was detected by time-resolved fluorometry, as described previously (22). We have carefully optimized this assay in terms of amounts of reagents used and incubation times to obtain the lowest possible detection limits. The optimal conditions are described in "Materials and Methods."

A typical calibration curve for this assay is shown in Fig. 1. The detection limit, defined as the concentration of analyte that can be distinguished from zero with 95% confidence, is 0.1 μg/l, and the dynamic range extends to 50 μg/l. Within-run and day-to-day precision studies (10 runs over 2 weeks) yielded coefficients of variation <10% within the measurement range. Recovery of added recombinant hK11 to serum averaged 50% (Table 1). We have further evaluated the cross-reactivity of this assay against other homologous kallikreins. We found no detectable cross-reactivity from hK2, hK4, hK6, hK10, and hK13 when these recombinant proteins (produced in-house) were tested at levels up to 1000 μg/l. For PSA (hK3), we detected some cross-reactivity when the PSA used was purified from seminal plasma. At 1,000 and 10,000 μg/l of seminal plasma PSA, the hK11 equivalent concentrations were 0.23 and 3.2 μg/l, respectively,

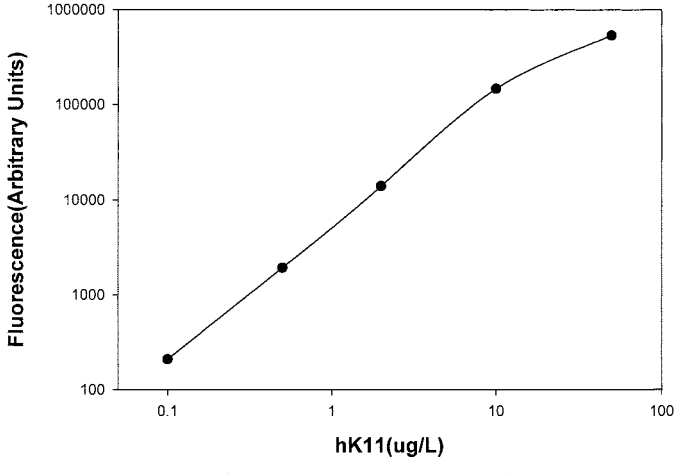

Fig. 1. Calibration curve of the newly developed hK11 immunofluorometric assay. The assay has a dynamic range of 0.1 μg/l (lowest detection limit) to 50 μg/l. The fluorescence of the zero standard was subtracted from all other measurements.

Table 1 *Recovery of added recombinant hK11 to human serum*

Sample	hK11, μg/l			
	Initially present	Added	Recovered	% recovery
60 g/l bovine serum albumin (control)	0	4.9	4.9	100
		16.9	16.9	100
Male serum #1	0.27	4.9	2.2	46
		16.9	8.6	51
Male serum #2	0.17	4.9	2.7	55
		16.9	9.2	55
Female serum #1	0.24	4.9	2.4	48
		16.9	8.0	47
Female serum #2	0.23	4.9	2.4	48
		16.9	8.6	51
Average				50

yielding an average cross-reactivity of 0.028%. However, when we tested the cross-reactivity with recombinant PSA, produced in bacteria, the cross-reactivity was much less (0.0003%). We thus concluded that the higher cross-reactivity found with seminal plasma PSA was likely attributable to hK11 contamination in this preparation. Further evidence that PSA does not cross-react with the hK11 immunoassay is provided below.

To study the distribution of hK11 protein in various human tissues, we have prepared cytosolic extracts, as described in "Materials and Methods" and quantified hK11 by the developed immunoassay. All values were corrected for the total protein content of the extracts. The data are shown in Fig. 2. Highest levels of hK11 were found in the prostate, followed by stomach, trachea, skin, and colon. Lower levels were found in pituitary, testis, lung, small intestine, and seminal vesicles. To study the cellular distribution of hK11, we have immunohistochemically localized it in paraffin-embedded tissue in intestinal epithelium (Fig. 3, *A* and *B*). Staining was restricted to the cytoplasm of epithelial cells.

We have further tested for the presence of hK11 in various biological fluids. The data are shown in Table 2. We detected hK11 in all fluids tested, with highest levels seen in amniotic fluid and milk of lactating women. The presence of hK11 in these fluids provides further evidence that hK11 is a secreted protein.

We have further quantified hK11 in seminal plasma, given the fact that this serine protease is present at highest levels in the prostate gland (Fig. 2). We have also quantified hK11 in five different prostatic tissue extracts, along with PSA (hK3), to establish their relative abundances. These data are shown in Table 3. hK11 concentration in seminal plasma is, on average, >100-fold higher than in any other biological fluid shown in Table 2. In the prostatic tissue extracts, the levels of hK11 are ~250 times lower than PSA levels, and there is no apparent correlation between PSA and hK11 levels. In seminal plasma, the levels of hK11 are also ~300 times lower than PSA. The lack of correlation between PSA and hK11 concentration in seminal plasma (Table 3) further suggests that our assay is not affected by the relatively huge amounts of PSA in this fluid. Another prostatic kallikrein, hK2, is present in seminal plasma at levels approximately 100–500 times lower than PSA (25). Thus, hK11 appears to be present in seminal plasma at levels 300 times lower than PSA and at levels roughly equivalent to those of hK2.

We have previously established tissue culture systems for studying the hormonal regulation of hK3 and hK2 (23). We used the cell lines LNCaP (prostatic carcinoma), PC-3 (AR; a prostatic carcinoma cell line stably transfected with androgen receptor), MCF-7 (breast carcinoma), MFM-223 (breast carcinoma), ZR-75 (breast carcinoma), BT-474 (breast carcinoma), T-47D (breast carcinoma), BT20 (breast carcinoma), and BG-1 (ovarian carcinoma). From all of these cell lines, only two (MCF-7 and BT-474) were able to produce and secrete detectable hK11 upon hormonal stimulation. As can be seen from Fig. 4, hK11 protein production is highly stimulated, mainly by estradiol in both cell lines, and to a lesser degree by other steroid hormones. In contrast, PSA (hK3) is highly up-regulated by dihydrotestosterone and the progestin norgestrel in BT-474 cells. In accordance with previous data, we did not find any production of PSA in the MCF-7 cell line (23). These data strongly suggest that the *KLK11* gene is up-regulated mainly by estrogens in these cell lines.

We have quantified hK11 in the serum of 40 apparently healthy females (ages 25 to 60 years) and 32 males (ages 30 to 65 years). Males have approximately three times higher levels, apparently because of the presence of the prostate. The medians of males (0.32 μg/l) and females (0.11 μg/l) differ significantly ($P < 0.01$ by Mann-Whitney test). For further analyses, we considered the upper reference range for normal persons as 0.25 μg/l for women and 0.50 μg/l for men (95th percentile).

We then analyzed a total of 114 serum samples from patients with various malignancies to examine whether hK11 is elevated in any of them. The data are presented in Table 4. Highest percentages of hK11 elevations were seen in patients with ovarian and prostate cancers. These data should be considered as preliminary, because the types of malignancies tested are limited and the number of patients in each group is small. The immunohistochemical localization of hK11 in an ovarian cancer tissue is shown in Fig. 3, *C* and *D*.

To examine the molecular forms of hK11 in seminal plasma and serum, as determined by our assay, we separated, on a gel filtration column, one seminal plasma and one serum sample with high hK11. The data are shown in Fig. 5. hK11 in seminal plasma elutes as a single peak corresponding to a molecular weight of M_r 30,000 (free hK11). In serum, in addition to the major M_r 30,000 form, there is a small peak (<10%) corresponding to a molecular mass of ~100 kDa. This may represent hK11 bound to serum proteinase inhibitors, as has been shown for PSA (26, 27).

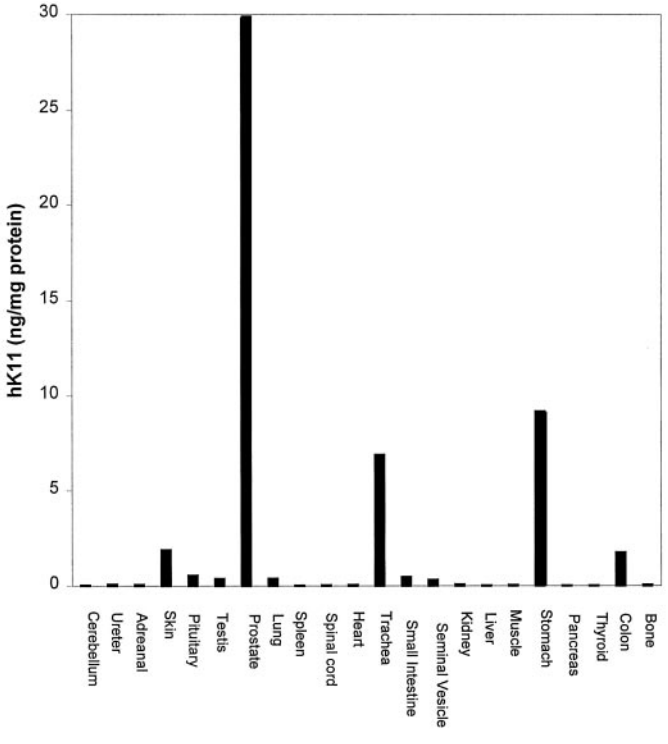

Fig. 2. hK11 content of cytosolic extracts of various human tissues. All hK11 concentrations were corrected for the amount of total protein. For details and discussion, see text.

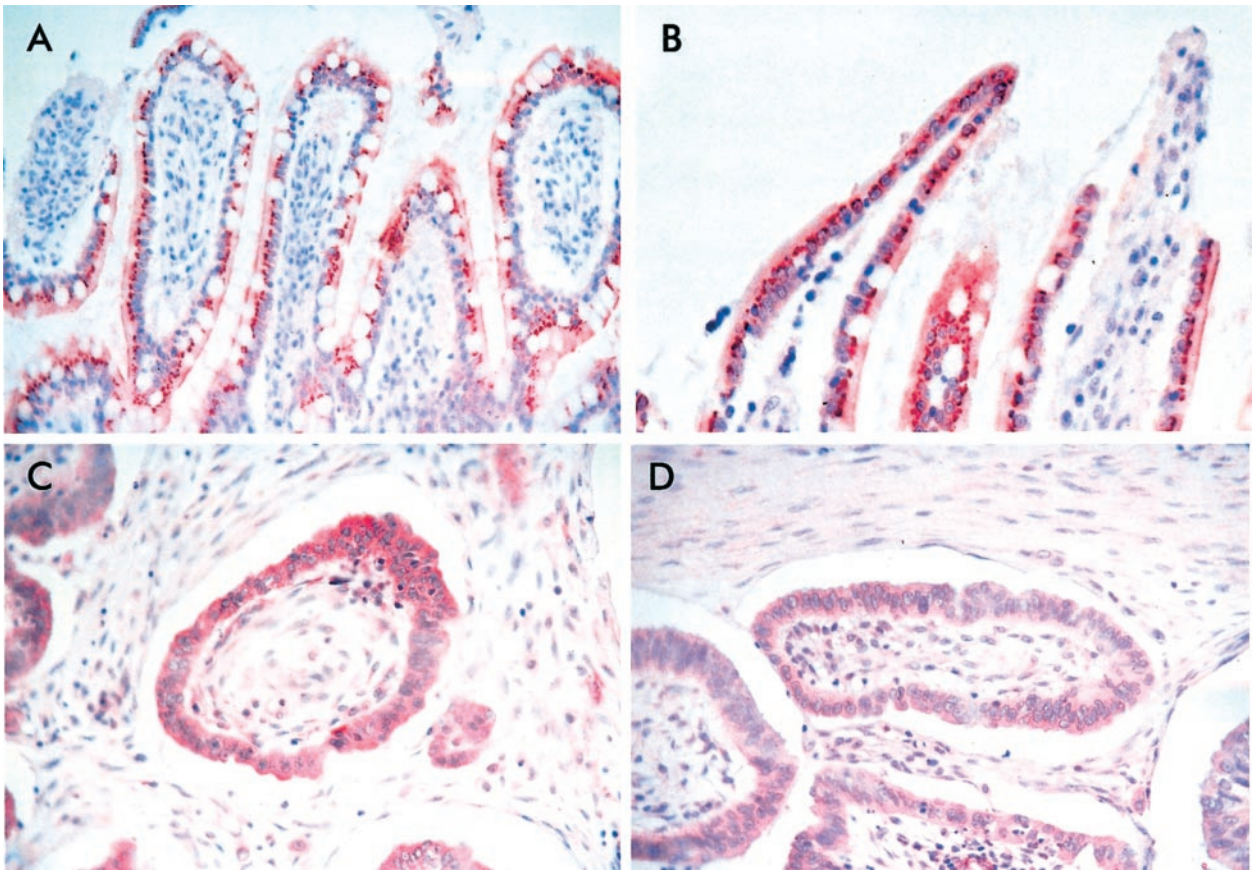

Fig. 3. Immunohistochemical localization of hK11 protein in tissues. Staining was performed with a monoclonal anti-hK11 antibody, as described in "Materials and Methods." *A*, intense staining in the supranuclear cytoplasm of small intestinal epithelial cells (×400). *B*, another section of the same tissue as in *A*. *C*, immunohistochemical staining of hK11 in epithelial cells of invasive papillary serous carcinoma of ovary (×400). *D*, another section of the same tissue as in *C*.

DISCUSSION

Among all known cancer biomarkers, PSA is the most valuable, because of its tissue specificity. Elevated serum PSA levels are seen in patients with prostatic carcinoma, and the test is widely used for diagnosis and monitoring of this disease. PSA is a member of the human tissue kallikrein gene family, and it is a secreted serine protease of 30-kDa molecular mass (1–4). Another member of this family, hK2, is an emerging biomarker for prostatic carcinoma (2). More recently, two other members of the kallikrein gene family, hK6 and hK10, have been proposed as new biomarkers for ovarian carcinoma (5, 6). Although there are now 15 known kallikrein genes, many family members have not been studied in detail (3, 4). We have reviewed recently the potential utility of kallikreins as cancer biomarkers (28). The success of other kallikreins as cancer biomarkers has prompted us to speculate that hK11 may also represent a novel biomarker. However, no methods are currently available for hK11 quantification in biological fluids or tissues.

We have produced recombinant hK11 protein in baculovirus, yeast, and bacterial expression systems. These proteins were highly purified by chromatography and used as immunogens to produce monoclonal and polyclonal antibodies. We used these antibodies to develop a highly sensitive immunoassay that is suitable for hK11 quantification in biological fluids and tissue extracts. Similar to a few other kallikreins (hK2, hK3, hK4, hK6, and hK10; Refs. 3, 4), hK11 is highly expressed in the prostate gland and to a lower degree in a number of other tissues (Fig. 2). Many biological fluids, including amniotic fluid and milk of lactating women, contain considerable amounts of hK11 (Table 2). However, highest levels are sheen in seminal plasma (Table 3).

hK11 is secreted by epithelial cells and has been immunolocalized in the supranuclear compartment, likely representing the Golgi apparatus of these cells (Fig. 3). Similar to many other members of this family, hK11 is up-regulated by steroid hormones, especially estradiol in two breast cancer cell lines (Fig. 4). Other members of this family

Table 2 *Concentration of hK11 in biological fluids*

	hK11, μg/l Sample number					
Fluid	1	2	3	4	5	6
Milk of lactating women	0.8	40	1.6	9.4	0.7	8.1
Amniotic fluid	5.2	45	2.0	7.8	10.5	11.3
Cerebrospinal fluid	2.9	3.0	1.5	1.6	1.3	1.7
Follicular fluid	0.5	2.7	0.7	7.3	0.6	2.2
Breast cancer cytosol	0.16	0.13	<0.1	0.31	0.1	0.8

Table 3 *Concentrations of PSA (hK3) and hK11 in five prostatic tissue extracts and five seminal plasma samples*

	PSA, μg/l	hK11, μg/l
Prostatic tissue extracts		
1	69,000	766
2	11,000	192
3	12,000	146
4	57,000	204
5	192,000	428
Seminal plasma samples		
1	3.5×10^6	2.8×10^3
2	1.1×10^6	1.7×10^3
3	0.3×10^6	1.4×10^3
4	0.9×10^6	3.0×10^3
5	0.6×10^6	3.4×10^3

(*e.g.*, PSA, hK2, and hK4) are up-regulated by androgens (3, 4, 23), whereas other kallikreins are also up-regulated by estrogens (3, 4, 29).

Our assay detects mainly the free form of hK11 in biological fluids (Fig. 5). Our data with serum suggest that hK11 may also be present in a complexed form with proteinase inhibitors, such as other kallikreins (26, 27). However, we do not know whether the traces of bound hK11 (Fig. 5*A*) represent the true concentration of this analyte or whether our assay does not efficiently measure the complex form of this serine protease. More studies will be necessary to delineate this issue. The lower recovery in serum (~50%; Table 1) further suggests that hK11 may bind to proteinase inhibitors that inhibit or partially inhibit its immunological activity in our assay, upon entrance into the circulation.

Although hK11 is present in the prostate, its concentration is substantially lower than PSA (Table 3). However, it appears that hK11 and hK2 concentrations are approximately equal in both prostatic tissue extracts and seminal plasma (25). It will be interesting to examine the biological role of this kallikrein in prostatic tissue and its secretions. It has been shown previously that PSA can cleave semenogelins and facilitate semen liquifaction (30). Additionally, hK2 can activate the pro-form of PSA (31–33). More recently, hK15, another kallikrein expressed in the prostate (12), was shown to activate the pro-form of PSA more efficiently than hK2 (34). It will be interesting to examine whether hK11 also participates in this cascade of activation reactions among kallikreins expressed in the prostate.

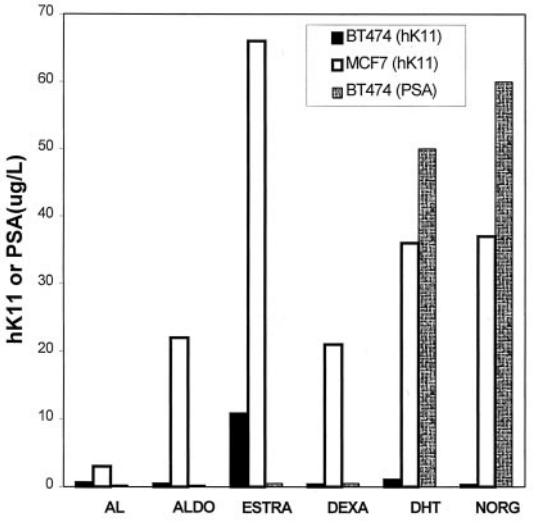

Fig. 4. Hormonal regulation of hK11 production in the breast carcinoma cell lines BT-474 and MCF-7. Highest hK11 protein concentration in tissue culture supernatants was seen in cells treated with estradiol. In BT-474 cells, highest levels of PSA in tissue culture supernatants were seen after induction with dihydrotestosterone and norgestrel, as described previously (23). *AL*, alcohol (negative control); *ALDO*, aldosterone; *ESTRA*, estradiol; *DEXA*, dexamethasone; *DHT*, dihydrotestosterone; *NORG*, norgestrel. For more details, see text.

Table 4 *Concentration of hK11 in sera of patients with various malignancies*

Malignancy	No. of serum samples	Patients (%) with hK11 >0.50 μg/l[a]	Patients (%) with hK11 >1 μg/l
Prostate cancer	20	12 (60%)	6 (30%)
Ovarian cancer	20	10 (50%)	8 (40%)
Medullary thyroid carcinoma	15	5 (33%)	1 (7%)
Colon cancer	28	6 (21%)	2 (7%)
Lung cancer	20	0 (0%)	0 (0%)
Pancreas	11	0 (0%)	0 (0%)

[a] This value represents the 95th percentile of healthy males. For women with ovarian cancer, 70% of them had hK11 >0.25 μg/l (95th percentile of healthy women).

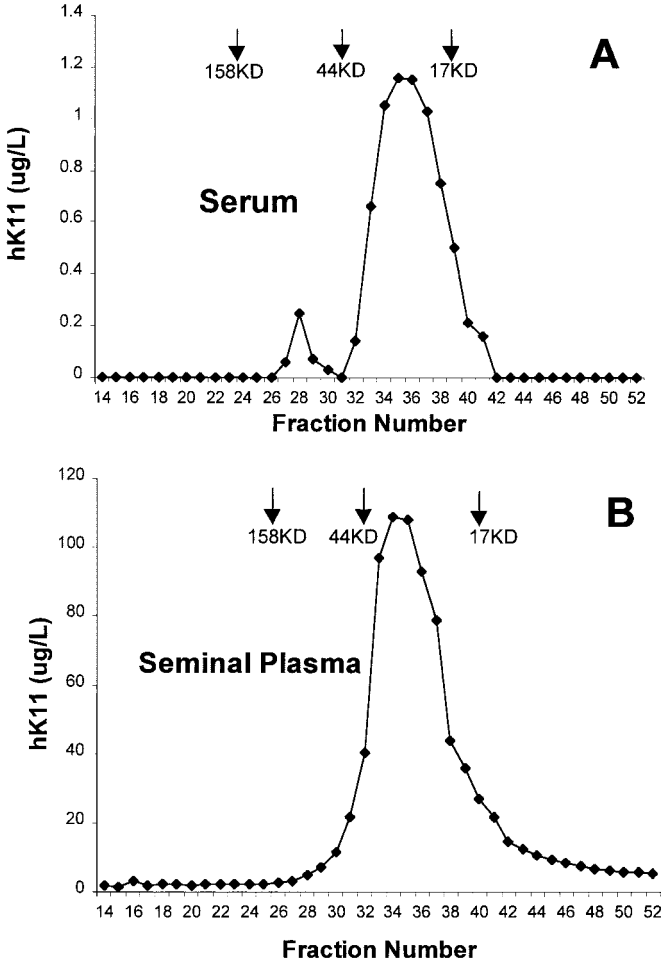

Fig. 5. High-performance liquid chromatographic separation on a gel filtration column of a serum sample (*A*) and a seminal plasma sample (*B*). In serum, a major peak around 33 kDa is shown along with a small peak around 100 kDa. The major peak represents the free form of hK11. In seminal plasma, only the free form of this enzyme is detectable. For discussion, see text.

The availability of recombinant hK11 protein will facilitate further studies into the understanding of the physiological functions of this serine protease in the prostate and other tissues.

Our preliminary investigations indicate that serum hK11 concentration is elevated in the majority of patients with ovarian and prostate cancer (Table 4). Because the malignancies and number of serum samples tested were limited, these data should be considered preliminary. We were able to immunohistochemically localize hK11 protein in ovarian cancer tissue (Fig. 3). Positivity was predominantly seen in the cytoplasm of tumor cells. It will be worthwhile to examine whether this biomarker has utility in the early diagnosis of ovarian cancer, in combination with other markers and in the differential diagnosis between prostate cancer and benign prostatic hyperplasia. These possible applications are of great clinical importance.

In conclusion, we present, to our knowledge, the first method for hK11 quantification and provide information regarding its tissue expression, hormonal regulation, and possible diagnostic value as an ovarian and prostatic cancer biomarker. The availability of this technology will allow more detailed investigations in the future.

REFERENCES

1. Diamandis, E. P. Prostate specific antigen—its usefulness in clinical medicine. Trends Endocrinol. Metab., *9:* 310–316, 1998.

2. Rittenhouse, H. G., Finlay, J. A., Mikolajczyk, S. D., and Partin, A. W. Human kallikrein 2 (hK2) and prostate-specific antigen (PSA): two closely related, but distinct, kallikreins in the prostate. Crit. Rev. Clin. Lab. Sci., *35:* 275–368, 1998.
3. Diamandis, E. P., Yousef, G. M., Luo, L. Y., Magklara, A., and Obiezu, C. V. The human kallikrein gene family—implications in carcinogenesis. Trends Endocrinol. Metab., *11:* 54–60, 2000.
4. Yousef, G. M., and Diamandis, E. P. The new human tissue kallikrein gene family: structure, function and association to disease. Endocr. Rev., *22:* 184–204, 2001.
5. Diamandis, E. P., Yousef, G. M., Soosaipillai, A. R., and Bunting, P. Human kallikrein 6 (zyme/protease M/neurosin): a new serum biomarker of ovarian carcinoma. Clin. Biochem., *33:* 579–583, 2000.
6. Luo, L-Y., Bunting, P., Scorilas, A., and Diamandis, E. P. Human kallikrein 10: a novel tumor marker for ovarian carcinoma? Clin. Chim. Acta, *306:* 111–118, 2001.
7. Obiezu, C. V., Scorilas, A., Katsaros, D., Massobrio, M., Yousef, G. M., Fracchioli, S., Rigault de la Longrais, I. A., Arisio, R., and Diamandis, E. P. Higher human kallikrein gene 4 (*KLK4*) expression indicates poor prognosis of ovarian cancer patients. Clin. Cancer Res., *7:* 2380–2386, 2001.
8. Kim, H., Scorilas, A., Katsaros, D., Yousef, G. M., Massobrio, M., Fracchioli, S., Piccinno, R., Gordini, G., and Diamandis, E. P. Human kallikrein gene 5 (*KLK5*) expression is an indicator of poor prognosis in ovarian cancer. Br. J. Cancer, *84:* 643–650, 2001.
9. Hoffman, B. R., Katsaros, D., Scorilas, A., Diamandis, P., Fracchioli S., Rigault de la Longrais, I. A., and Diamandis, E. P. Tumor specific activity of kallikrein 6 protein is a prognostic marker of ovarian carcinoma. Proc. Am. Assoc. Cancer Res., *42:* 46–47, 2001.
10. Magklara, A., Scorilas, A., Katsaros, D., Massobrio, M., Yousef, G. M., Fracchioli, S., Danese, S., and Diamandis, E. P. The human *KLK8* (*neuropsin/ovasin*) gene: identification of two novel splice variants and its prognostic value in ovarian cancer. Clin. Cancer Res., *7:* 806–811, 2001.
11. Luo, L. Y., Katsaros, D., Scorilas, A., Fracchioli, S., Piccinno, R., Rigault de la Longrais, I. A., Howarth, D. J. C., and Diamandis, E. P. Prognostic value of human kallikrein 10 expression in epithelial ovarian carcinoma. Clin. Cancer Res., *7:* 2372–2379, 2001.
12. Yousef, G. M., Scorials, A., Jung, K., Ahsworth, L. K., and Diamandis, E. P. Molecular cloning of the human kallikrein 15 gene (*KLK15*): up-regulation in prostate cancer. J. Biol. Chem., *276:* 53–61, 2001.
13. Luo, L. Y., Rajpert-De Meyts, E., Jung, K., and Diamandis, E. P. Expression of the normal epithelial cell-specific 1 (*NES1*; *KLK10*) candidate tumor suppressor gene in normal and malignant testicular tissue. Br. J. Cancer, *85:* 220–224, 2001.
14. Yousef, G. M., Magklara, A., Chang, A., Jung, K., and Diamandis, E. P. Cloning of a new member of the human kallikrein gene family, *KLK14*, which is down-regulated in different malignancies. Cancer Res., *61:* 3425–3431, 2001.
15. Tanimoto, H., Underwood, L. J., Shigemasa, K., Yan, Y., Clarke, J., and O'Brien, T. J. The stratum corneum chymotryptic enzyme that mediates shedding and desquamation of skill cells is highly over-expressed in ovarian tumor cells. Cancer (Phila.), *86:* 2074–2082, 1999.
16. Underwood, L. J., Tanimoto, H., Wang, Y., Shigemasa, K., Parmley, T. H., and O'Brien, T. J. Cloning of tumor-associated differentially expressed gene-14, a novel serine protease overexpressed by ovarian carcinoma. Cancer Res., *59:* 4435–4439, 1999.
17. Yoshida, S., Taniguchi, M., Suemoto, T., Oka, T., He, X., and Shiosaka, S. cDNA cloning and expression of a novel serine protease, TLSP. Biochem. Biophys. Acta, *1399:* 225–228, 1998.
18. Diamandis, E. P., Yousef, G. M., Clements, J., Ashworth, L. K., Yoshida, S., Egelrud, T., Nelson, P. S., Shiosaka, S., Little, S., Lilja, H., Stenman, U. H., Rittenhouse, H. G., and Wain, H. New nomenclature for the human tissue kallikrein gene family. Clin. Chem., *46:* 1855–1858, 2000.
19. Yousef, G. M., Scorilas, A., and Diamandis, E. P. Genomic organization, mapping, tissue expression and hormonal regulation of trypsin-like serine protease (TLSP PRSS20), a new member of the human kallikrein gene family. Genomics, *63:* 88–96, 2000.
20. Luo, L. Y., Grass, L., Howarth, D. J. C., Thibault, P., Ong, H., and Diamandis, E. P. Immunofluorometric assay of human kallikrein 10 and its identification in biological fluids and tissues. Clin. Chem., *47:* 237–246, 2001.
21. Campbell, A. M. Production and purification of antibodies. *In:* E. P. Diamandis and T. K. Christopoulos (eds.), Immunoassay, pp. 95–115. San Diego: Academic Press, 1996.
22. Christopoulos, T. K., and Diamandis, E. P. Enzymatically amplified time-resolved fluorescence immunoassay with terbium chelates. Anal. Chem., *64:* 342–346, 1992.
23. Magklara, A., Grass, L., and Diamandis, E. P. Differential steroid hormone regulation of human glandular kallikrein (hK2) and prostate specific antigen (PSA) in breast cancer cell lines. Breast Cancer Res. Treat., *59:* 263–270, 2000.
24. Ferguson, R. A., Yu, H., Kalyvas, M., Zammit, S., and Diamandis, E. P. Ultrasensitive detection of prostate specific antigen by a time-resolved immunofluorometric assay and the Immulite® immunochemiluminescent third generation assay: potential applications in prostate and breast cancers. Clin. Chem., *42:* 675–684, 1996.
25. Black, M. H., Magklara, A., Obiezu, C. V., Melegos, D. N., and Diamandis, E. P. Development of an ultrasensitive immunoassay for human glandular kallikrein with no cross-reactivity from prostate-specific antigen. Clin. Chem., *45:* 790–799, 1999.
26. Stenman, U. H., Leinonen, J., Alfthan, H., Rannikko, S., Tuhkanen, K., and Alfthan, O. A complex between prostate-specific antigen and α1-antichymotrypsin is the major form of prostate-specific antigen in serum of patients with prostatic cancer: assay of the complex improves clinical sensitivity for cancer. Cancer Res., *51:* 222–226, 1991.
27. Christensson, A., Laurell, C. B., and Lilja, H. Enzymatic activity of prostate-specific antigen and its reaction with extracellular serine proteinase inhibitors. Eur. J. Biochem., *194:* 755–763, 1990.
28. Diamandis, E. P., and Yousef, G. M. Human tissue kallikrein gene family: a rich source of novel disease biomarkers. Expert Rev. Mol. Diagn., *1:* 182–190, 2001.
29. Luo, L. Y., Grass, L., and Diamandis, E. P. The normal epithelial cell-specific 1 (*NES1*) gene is up-regulated by steroid hormones in the breast carcinoma cell line BT-474. Anticancer Res, *20:* 981–986, 2000.
30. Lilja, H. A kallikrein-like serine protease in prostatic fluid cleaves the predominant seminal vesicle protein. J. Clin. Investig., *76:* 1899–1903, 1985.
31. Lovgren, J., Rajakoski, K., Karp, M., Lundwall, A., and Lilja, H. Activation of the zymogen form of prostate-specific antigen by human glandular kallikrein 2. Biochem. Biophys. Res. Commun., *238:* 549–555, 1997.
32. Kumar, A., Mikolajczyk, S. D., Goel, A. S., Millar, L. S., and Saedi, M. S. Expression of pro form of prostate-specific antigen by mammalian cells and its conversion to mature, active form by human kallikrein 2. Cancer Res., *57:* 3111–3114, 1997.
33. Takayama, T. K., Fujikawa, K., and Davie, E. W. Characterization of the precursor of prostate-specific antigen—activation by trypsin and by human glandular kallikrein. J. Biol. Chem., *272:* 21582–21588, 1997.
34. Takayama, T. K., Carter, C. A., and Deng, T. Activation of prostate-specific antigen precursor (pro-PSA) by a novel human prostatic serine protease identified by degeneration. Biochemistry, *40:* 1679–1687, 2001.