Laboratory Studies

Plasma Prorenin in Humans and Dogs
Species Differences and Further Evidence of a Systemic Activation Cascade

ESTHER A. WILCZYNSKI, B.SC. AND DANIEL H. OSMOND, PH.D.

SUMMARY We have studied the dog as a potential model for the human plasma prorenin-renin system. On a regular sodium intake, healthy conscious dogs apparently have a much lower plasma renin activity (PRA) than healthy human volunteers. Cryoactivation of prorenin is virtually absent in dogs, in contrast to that in humans, but becomes more effective after preacidification of the plasma. The concentration of trypsin required for optimal activation of prorenin is 6 to 10 times higher for dog plasma, revealing a prorenin:renin ratio about 10 times greater than in humans. Dialysis of posttrypsin plasma decreases the PRA, but it remains 5 times higher than in pretryptic plasma, indicating that activation is not totally dependent on any renin system component that has been rendered dialyzable by trypsin, e.g., substrate converted to tetradecapeptide (TDP). This argues against the view that trypsin activation is attributable to angiotensin production from TDP by the action of cathepsin D, rather than from new renin converted from prorenin. The posttryptic increase in PRA is evident whether plasma incubation is carried out at pH 6.0 or at 7.4, and can be largely blocked by pepstatin, which also implicates a prorenin-renin mechanism rather than TDP-cathepsin. The low PRA in dogs, the negligible cryoactivation and its improvement by preacidification, and the requirement and tolerance of high trypsin concentrations, all point to greater protease inhibition in dog plasma and/or departures from the enzyme(s) responsible for human prorenin activation. Moreover, the trypsin activation of prorenin is not completed quickly as in human plasma, but carries over into the posttryptic stage of angiotensin generation, even in the presence of excess soybean trypsin inhibitor (SBTI), and other potent inhibitors. Such ongoing prorenin activation cannot be attributed only to trypsin itself, nor to kallikrein (both are inhibited by SBTI), but rather to some other enzyme(s) derived by the action of trypsin. This new prorenin convertase activity (possibly renin itself) can be effectively transferred from trypsinized to control dog plasma, in which it greatly accelerates prorenin activation. Thus, contrary to other reports, dog plasma has a high content of activatable prorenin, and with appropriate methodological changes, the dog can be used as an animal model for physiological and biochemical studies of the prorenin-renin system. (Hypertension 5:277-285, 1983)

KEY WORDS • trypsin-activation • cryoactivation • pepstatin • non-serine proteases • inhibitors • autocatalysis

There is now abundant evidence in favor of an inactive renin precursor, often called "prorenin." In normal human plasma, prorenin has been activated in vitro by cryoactivation, or trypsin, or acid treatment. The mechanism by which activation occurs in vivo is not yet understood, but it is likely that enzymes of other blood cascades are involved. From the Department of Physiology, University of Toronto, Toronto, Ontario, Canada. Presented in part at the Joint Fall meeting of the American and Canadian Physiological Societies, October 12-17, 1980, and at the International Symposium on Inactive Renin, May 6-7, 1982, Porto Cervo, Italy. Supported by the Ontario Heart Foundation. Address for reprints: Daniel H. Osmond, Ph.D., Department of Physiology, Medical Sciences Building, University of Toronto, Toronto, Ontario, Canada M5S 1A8. Received March 1, 1982; revision accepted November 29, 1982.

277
For instance, rat plasma requires a higher concentration of trypsin for prorenin activation than does human plasma.17

This study presents techniques whereby prorenin can be demonstrated in dog plasma. We compare human and dog plasma, and present new evidence that tryptic activation is not simple, or direct, but probably requires mediation by one or more additional enzymes. We suggest that for certain kinds of studies the dog could probably serve as a suitable animal model, provided the appropriate activation methods are used.

**Materials and Methods**

**Plasma Preparation**

Six healthy male beagles, 13-16 kg, aged 12-20 months, and on an unrestricted diet were trained to require only minimal restraint during venipuncture. Blood samples were collected from the conscious dogs into EDTA (ethylenediamine tetraacetate, ammonium form, 15% solution in water, 0.3 ml/10 ml blood), and chilled immediately. The blood was centrifuged at 1500 x g, 4°C, for 20 minutes, and the plasmas separated and stored at −70°C until further assay. The human plasma pool was prepared in the same way from six healthy men on an unrestricted diet.

**Plasma Renin Activity**

Plasma renin activity (PRA) was determined as described previously,5,18 using an angiotensin I radioimmunoassay kit (RIA, New England Nuclear Medical Diagnostics Division, North Billerica, Massachusetts). Plasma samples were incubated for up to 30 minutes at 37°C, pH 6, in the presence of angiotensin-producing enzyme that results from tryptic activation of dog plasma, trypsinized plasmas (3 mg/ml, 10 minutes, 23°C) were incubated in the presence of the renin inhibitor pepstatin (pepstatin A, Sigma, P-4265). The pepstatin solution was prepared according to Guyene et al.,19 (13.7 mg pepstatin dissolved in 10 ml of acetic acid:methanol, 1:19, vol/vol; brought to a concentration of 10−3 M with 10 ml IN NaOH:methanol, 1:2, vol/vol), and added to plasma to give a final concentration of 10−5 M. The same volume of vehicle was added to the control plasma.

Following incubation of the plasmas at 37°C for 15 and 30 minutes, with, and without pepstatin, PRA was determined by RIA.

**Effect of pH on the PRA Incubation Step of Posttryptic Plasma**

To further determine whether trypsin-induced angiotensin I generation in dog plasma is related to an acid protease other than renin, the PRA incubation step at 37°C (Stage 2) was carried out both at pH 6.0 and pH 7.4, comparing the effects in human and dog plasma. Dog plasma (pool from two males) was incubated with trypsin, 3 mg/ml plasma (10 minutes, 23°C), and human plasma (pool from three men), with 0.5 mg/ml (10 min, 23°C). In each case, excess LBTI was added at the end of the 10 minutes of incubation. Activated plasmas, as well as nontrypsinized controls, were then incubated at 37°C for up to 30 minutes at pH 6.0 and pH 7.4, and PRA was determined by RIA.

**Effect of Dialysis on Posttryptic PRA in Dog Plasma**

Control and trypsin-activated dog plasma (3 mg/ml, 10 minutes, 23°C, followed by LBTI addition) were subjected to 24 hours of dialysis, pH 7.4 at 4°C. All
samples, including nondialyzed controls contained DFP (diisopropylfluorophosphate, Sigma, D-0879).

Determination of Involvement of Nonserine Proteases in Dog Plasma

Use of Inhibitor Cocktail

In human plasma that had been pretrypsinized for 10 minutes at 23°C (Stage 1 incubation), the subsequent rate of angiotensin generation at 37°C in the PRA step (Stage 2 incubation) was relatively constant over time. In contrast, dog plasma gave greater hourly angiotensin generation rates as Stage 2 incubation time exceeded beyond 15 minutes. This occurred in spite of the presence of excess LBTI added at the end of Stage 1, which should have completely neutralized all continuing trypsin activity in Stage 2. To determine whether such continuing posttrypsin activity was susceptible to protease inhibitors, we added a "cocktail" of inhibitors at the end of Stage 1, consisting of: LBTI (3 mg/ml), soybean trypsin inhibitor (SBTI, 3 mg/ml, Sigma, T-9003), benzamidine (8 mM, Sigma, B-6506), and polybrene (150 μg/ml, Sigma, P-4515). The control plasma samples were treated with trypsin plus all these inhibitors, added simultaneously, allowing no time for the trypsin to act.

Transfer of the Developed Posttrypsin Prorenin Activators

Small aliquots (50 μl) of plasma samples that had been treated with trypsin (3 mg/ml) for either 5 or 30 minutes before the addition of LBTI were transferred to untreated control plasma samples (300 μl), and incubated at 37°C for 60 minutes without further pH adjustment. The PRA of all samples was determined using suitable corrections for the transferred renin activity. In this manner all newly developed renin activity attributable to "seeding" with the 50 μl posttrypsin aliquot could be accounted for.

In some cases, the posttrypsin aliquot was boiled for 10 minutes prior to incubation (60 minutes, 37°C) with fresh plasma.

Results

Active Renin

The active renin in dog plasma was considerably lower than that found typically in normal human plasma (fig. 1). The difference seems great enough not to be attributable to any subtle differences in sodium and fluid volume status due to diet.

Cryoactivation

Cryoactivation has been found to be most effective in human plasma at a temperature as close to the freezing point as possible — around −5°C. Generally, a temperature of −4°C has been used in human studies to avoid freezing of the plasma. In dog plasma we noted a tendency to freeze solid at −4°C, and therefore used 0°C for cryoactivation. The effect of up to 42 days of cold incubation of human and dog plasmas is shown in figure 2. Human PRA increased stead-

![Figure 1. Active renin in human and dog plasmas. Average PRA values (± SEM) in terms of angiotensin I, ng/ml/hr, in untreated plasmas from six healthy men and six healthy male dogs. Numbers in parentheses represent the number of determinations.

![Figure 2. Effect of prolonged cryoactivation on human and dog PRA. Average PRA values (± SEM) in plasmas from six healthy men and six healthy male dogs after incubation at 0°C for up to 42 days. All the renin indicated above the horizontal broken line is "new renin" (prorenin) due to cryoactivation of human plasma. In dog plasma, cryoactivation had very little effect, and no prorenin is singled out.]
Preacidification of dog plasma for 3 hours followed by pH restoration to 7.4 and then 7 days of cold incubation resulted in some cryoactivation, but this was accompanied by a loss of active renin (fig. 3). Such loss can apparently be attributed to dialysis itself because it also occurred in samples dialyzed at pH 7.4. Overall, the effect of preacidification for 3 hours on the efficacy of cryoactivation was only modest.

**Tryptic Activation**

**Titration of Plasma with Trypsin**

Activation of prorenin in human plasma appeared maximal with 1 mg of trypsin per ml of plasma which suggests that this concentration is optimal or close to it (fig. 4). Higher trypsin concentrations tended to become destructive, and PRA decreased. In dog plasma, however, trypsin was relatively ineffective at 1 mg/ml, and maximal activation occurred at closer to 5 mg/ml, revealing a much larger prorenin component than in human plasma (50 vs 15 ng/ml/hr, fig. 4).

**Time Course of Tryptic Activation**

In this experiment, plasma samples were not incubated with trypsin for the usual 10 minutes but, instead, for 1 to 60 minutes at 23°C; excess LBTI was added to stop the reaction at the end of each selected interval (fig. 5). It can be seen that about 90% of prorenin activation in human plasma occurred within the first minute, as observed previously. Thereafter, PRA remained relatively constant for 30 minutes, before destructive effects of trypsin became evident. In contrast, the PRA continued to rise in trypsinized dog plasma for up to 30 minutes. Only about 15% of trypsinic activation occurred within the first minute.
Effect of Pepstatin on Tryptic Activation in Dog Plasma

The renin inhibitor pepstatin, added to trypsin-activated dog plasma virtually eliminated the active renin component and drastically reduced the total PRA (fig. 6). Since trypsin was already neutralized by endogenous inhibitors and excess LBTI, these data imply that posttrypsinic increases in angiotensin I generation are truly renin-mediated, and are not the product of direct trypsic activity on renin substrate, or some other substrate.

Effect of pH on the PRA Incubation Step of Posttrypsinic Plasma

When plasmas were incubated at pH 7.4 rather than the usual pH 6.0 in the 37°C PRA incubation step (Stage 2), prorenin revealed by trypsinic activation was reduced to a similar extent in both human and dog plasmas (41.6% and 41.2%, respectively, table 1). There was still a marked increase in dog PRA after trypsin even when Stage 2 incubation was carried out at pH 7.4. This indicates that the enzyme responsible is active at a physiological pH, and is therefore unlikely to be an acid protease with a pH optimum as low as that of the proposed plasma cathepsins. 11

Effect of Dialysis on Posttrypsinic PRA in Dog Plasma

Dialysis of pre- and posttrypsin dog plasmas for 24 hours, pH 7.4, 4°C resulted in a decrease in PRA when compared to their nondialyzed counterparts (table 2), as also reported by Gallagher et al. 11 The PRA in nontrypsinized plasmas fell from 2.5 ± 0.2 to 1.2 ± 0.1 ng angiotensin I/ml plasma/hr, while in posttrypsin samples, the PRA decreased from 28.2 ± 0.4 to 6.7 ± 0.1 ng/ml/hr. The volume of all dialysis samples increased by approximately 25% during the 24-hour period. This change was accounted for in the calculations of PRA.

Involvement of Nonserine Proteases on Prorenin Activation in Dog Plasma

Effects of Inhibitor Cocktail

After 10 minutes of incubation with trypsin at 23°C and the addition of excess LBTI, plasmas were incubated at 37°C, pH 6, to allow angiotensin I generation for various time intervals. In human plasma the computed hourly rate of angiotensin I generation turned out to be constant whether incubation proceeded for 15, 30, 45 or 60 minutes (fig. 7). In the dog, however, the hourly rate of angiotensin I generation increased with the length of incubation time. Thus, even though trypsin must have been neutralized by excess LBTI, there was continuation of some after-effect of trypsin, and the rate of angiotensin generation continued to increase, as though there was also an ongoing increase in the concentration of renin.

Such enhancement of the hourly generation rate could not be prevented by several broad-spectrum serine, or other protease inhibitors, i.e., SBTI,22 benzamidine,23,24 and polybrene,25 used individually or in combination.

Table 1. Effect of pH on PRA and Prorenin (Angiotensin Generation, Stage 2 Incubation, 37°C) in Pre- and Posttrypsinic Plasmas from Humans and Dogs

<table>
<thead>
<tr>
<th></th>
<th>Human (pool, n = 3)</th>
<th>Dog (pool, n = 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(ng/ml/hr)</td>
<td>(ng/ml/hr)</td>
</tr>
<tr>
<td>pH 6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretrypsin</td>
<td>3.5 ± 0.1*</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Posttrypsin</td>
<td>5.6 ± 0.4</td>
<td>18.5 ± 1.5</td>
</tr>
<tr>
<td>Prorenin</td>
<td>2.1 ± 0.1</td>
<td>17.2 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>± SEM</td>
<td>± SEM</td>
</tr>
</tbody>
</table>
| *Mean PRA (ng/ml/hr) ± SEM, five determinations each.  
†Trypsin concentration, 0.5 mg/ml in human, 3 mg/ml in dog, 10 minutes, 23°C.  
‡Prorenin determined as posttrypsinic PRA minus control PRA.

Table 2. Effect of Dialysis (24 hours, 4°C, pH 7.4) on PRA of Pre- and Posttrypsinic Dog Plasma (Pool, n = 2)

<table>
<thead>
<tr>
<th></th>
<th>Before dialysis</th>
<th>After dialysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ng/ml/hr)</td>
<td>(ng/ml/hr)</td>
<td>(ng/ml/hr)</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretrypsin</td>
<td>2.5 ± 0.2*</td>
<td>1.2 ± 0.1</td>
</tr>
<tr>
<td>Posttrypsin‡</td>
<td>28.2 ± 0.4</td>
<td>6.7 ± 0.1</td>
</tr>
</tbody>
</table>
| *Mean PRA ± SEM, three determinations each.  
‡Trypsin concentration 3 mg/ml, 10 minutes, 23°C.
FIGURE 7. Effect of prolonged Stage 2 incubation (37°C) on pretrypsinized dog and human plasmas. Dog plasmas (six male pool, six determinations) and human plasmas (six male pool, two determinations) were incubated in Stage 1 with trypsin (3 mg/ml for dogs, 0.5 mg/ml for humans, for 10 minutes at 23°C). Samples were then incubated in Stage 2 at 37°C, pH 6, for 15, 30, 45, and 60 minutes, and angiotensin generation was determined and expressed as an hourly rate (averages ± SEM). In dog, but not human, plasmas, the hourly rate of angiotensin generation in Stage 2 continued to rise throughout.

Transfer of the Developed Nontryptic Activator of Prorenin

Transfer of small aliquots of pretrypsinized plasma to control untreated dog plasma provoked a 300% to 400% increase in PRA (fig. 8). It appeared that some active prorenin "convertase(s)" resulting from trypsin was being transferred to the normal plasma. Samples in which formation of this convertase had been prevented by the simultaneous addition of LBTI exhibited no such activation. It would appear, then, that this convertase activity results from the action of trypsin, but is not itself completely inhibited by LBTI or by endogenous inhibitors of dog plasma.

When the 50 µl posttrypsin aliquot had been held 10 minutes in boiling water before transfer to 300 µl control plasma, no "new" renin activity was generated. In other words, boiling destroyed the prorenin "convertase" activity.

Discussion

Research on human plasma "prorenin" has progressed rapidly in recent years. The availability of animal models now undoubtedly facilitates further advances, but unexpected hindrances have been encountered. Using conventional techniques, in our earliest work we showed that dogs appeared to have an unimpressive concentration of plasma prorenin, while rabbits and rats had even lower concentrations. It was not clear whether these findings represented true species differences or merely experimental variables such as stress, anesthesia, rapid loss by spontaneous conversion of prorenin after blood collection, or a different efficacy of trypsin as a prorenin activator among the species. Accordingly, it became necessary to investigate the activation of plasma prorenin in dogs and other animals in greater detail.

We consistently observe that the PRA of healthy, conscious resting dogs on a regular sodium diet is far lower than the PRA values of normal human volunteers. With our assay procedure, employing minimal plasma dilution and short incubation periods, normal human PRA values frequently average 5 ng/ml/hr, as is the case here (fig. 1). In comparison, normal conscious dog PRA values are about 1 ng/ml/hr. This difference could represent a true species difference, or some idiosyncrasy of fluid and electrolyte status. In addition, dog plasma may be concentrated in protease inhibi-
PLASMA PRORENNIN IN HUMANS AND DOGS/Wilczynski and Osmond 283
tors, or short of a convertase enzyme, such that pro-
renin conversion to renin in vivo as well as in vitro
(i.e., after blood collection) is damped, resulting in a
characteristically low PRA.

Whereas cryoactivation of prorenin is highly effec-
tive in human plasma, it is virtually undemonstra-
table in dog plasma (fig. 2). Cryoactivation at 0°C for up
to 42 days produced only a trivial increase in PRA,
indicating a virtual absence of conventional prorenin
activation in dogs, in contrast to the 360% increase
observed under comparable conditions in humans.
Such a lack of cryoactivation has also been reported by
Gallagher et al. after incubation of dog plasma at
-4°C for 4 days.

We therefore attempted to cryoactivate dog plasma
that had been previously acidified. Such brief acidifi-
cation does not necessarily inactivate dog renin sub-
strate, but it probably destroys some of the protease
inhibitors in plasma, and therefore should promote
cryoactivation. This was, in fact, observed experimen-
tally (fig. 3), indicating that cryoactivation can be fa-
cilitated, but presumably not to full potential under
present conditions, as compared to trypsinic activa-
tion.

It is unclear whether more prolonged acidification
would have promoted additional cryoactivation with-
out destroying substrate, but, certainly dog plasma
does not lend itself to simple cryoactivation. Its con-
tent of protease inhibitors may be high, and/or one or
more of the cooperating proteases may be lacking.

Trypsin, used in the low concentrations that are ef-
fective in human plasma, failed to activate dog plasma
prorenin significantly. Whereas trypsin concentrations
under 1 mg/ml are highly effective in human plasma,
and 1 to 2 mg/ml begin to be destructive in some cases,
such concentrations barely activate plasma prorenin in
dogs (fig. 4). The highest degree of activation in most
dogs was observed with 5 mg/ml. These results are in
line with those of Gallagher et al. who showed a
higher PRA resulting from trypsin at 2 mg as compared
with 0.6 mg/ml plasma, using a trypsin preparation
with a specific activity about 30% higher than the one
we used.

Gallagher et al. attributed such a raised PRA not to
the activation of prorenin, but to the formation of
angiotensin I by a new pathway. They suggested that
trypsin cleaved native globulin renin substrate to a
tetradecapeptide (TDP) substrate, which became sus-
ceptible to endogenous cathepsin D. It was from this
newly formed TDP and cathepsin D that extra angio-
tensin was formed, raising the PRA value, and creating
a false impression of prorenin activation. The TDP,
being a relatively small peptide, could be dialyzed out
so that lower PRA and apparent substrate values were
registered after dialysis of trypsinized plasmas.

Several counterarguments to this interpretation can
be brought forward. First, the original demonstration
of TDP production by trypsin was in horse plasma
under different, more drastic, conditions, the results
of which are not necessarily applicable to the study of
Gallagher et al., or the present one. Second, the evi-
dence adduced by Gallagher et al. is inferential, not
actual. They did not actually demonstrate the existence
of higher TDP levels, or its cleavage by cathepsin D.
They only showed that dialysis depressed the PRA, for
which other plausible explanations than the removal of
TDP are also possible. Third, Cooper et al. showed
that in human plasma, at least, TDP plays only a trivial
role in posttrypsinic activation. It is unlikely that in dogs
TDP would account for all such activation. Fourth,
Gallagher et al. reported that "trypsin shifted the pH
optimun curve towards the alkaline range in normal
(nephric) dog plasma. They did not mention that
cathepsin D would be essentially inoperative at alkali-
ne pH, and therefore was not likely to be the enzyme
mediating the observed trypsinic activation. On the other
hand, renin formed from prorenin would be operative
at alkaline pH and is therefore the more likely mediator
of trypsinic activation.

Our experimental data further weaken the TDP-
cathepsin D hypothesis. We determined PRA values at
pH 6.0 and 7.4 in human and dog plasmas, with and
without pretrypsinization (table 1). As expected,
PRAs in both species were higher at pH 6, which is
generally regarded as a near-optimal pH for renin.
However, the PRAs at pH 7.4 were also quite high,
and the differences between pH 6 and 7.4 values were
comparable in humans and dogs. If the operative
angiotensin-generating system had been TDP-cathepsin,
virtually no activity should have been detectable at pH
7.4, and the differences between pH 6 and 7.4 values
should have been much more pronounced. They
should also have been far greater in dogs than in hu-
mans because Gallagher et al. attribute the TDP-cath-
espin D mechanism only to dogs. The fact that dogs
and humans had a similar pH 6 and 7.4 differential
argues against a TDP-cathepsin mechanism only in
dogs.

Moreover, we have found (table 2) that, while dialy-
sis of posttrypsinic plasma lowered the subsequent PRA
by 75%, a comparable lowering of about 50% was
observed in nontrypsinized plasma. In other words,
at least 50% of the decline in PRA is not attributable to
any postulated trypsinic alteration of substrate that ren-
der it dialyzable. Plasma dilution (affecting substrate
concentration and therefore renin-substrate kinetics),
or some other unknown consequence of dialysis, may
contribute to subsequent PRA reduction. Further, Gal-
lagher et al. trypsinized plasma at 4°C for 60 minutes,
and compared with 10 minutes at 23°C in our experi-
ments. Our method of prorenin activation yields much
lower 4°C RIA blank values than theirs, implying less
destructive activity by trypsin, with less formation of
"unphysiological" cross-reactive peptides that may,
or may not, include TDP. Indeed, the apparently more
destructive conditions of Gallagher et al. may have
produced effects that are not at all applicable to our
own experiments.

We have demonstrated (table 2) that dog plasma
dialysis after trypsin depresses PRA from what it
would have been if dialysis had not been carried out.
Nevertheless, the postdialysis, posttrypsin PRA is
500% higher than its predialysis nontrypsinized con-
trol. In other words, tryptic activation survives dialysis, and cannot be attributed only to TDP, which would have been removed by dialysis. Even if TDP was part of the activation process, it certainly does not account for all of it.

To further implicate renin rather than TDP-cathepsin as the enzyme that results from tryptic activation of dog plasma prorenin, we added the potent acid protease inhibitor pepstatin to plasma, just before the PRA incubation step (Stage 2), but after trypsin had been operative for 10 minutes at 23°C. LBTI, maleate buffer, angiotensinase inhibitors, and pepstatin were added concurrently (Methods, fig. 7). The results show a substantial reduction in posttrypsin PRA, which may be interpreted as an inhibition of renin.

Pepstatin inhibits hog cathepsin D at Ki < 5 x 10^{-10} M, and rat renin at Ki approximately 6 x 10^{-7} M at pH 5.5, and could therefore be expected to inhibit dog renin at our much higher concentration of 1 x 10^{-3} M at pH 6.0 (see Methods). Pepstatin is known to be effective against dog renin which has a similar amino-acid composition to that of hog renin, to which pepstatin has an even greater affinity than to rat renin.

As indicated earlier, the enzyme activity produced by tryptic activation of dog plasma prorenin expressed itself strongly in terms of angiotensin I generation at a pH of 6.0, with 60% of the activity remaining at the pH of 7.4 (Table 1). Such activity is well beyond the effective pH range for cathepsin D. In addition, cathepsin D would probably have been more powerfully inhibited than renin by endogenous inhibitors in a plasma incubation mixture. This combination of experimental observations favors renin rather than cathepsin D as the main effective derivative of tryptic activation in dog plasma.

Evidence of a distinctive prorenin activation cascade in dog plasma is derived by contrast with human plasma. In humans, the action of trypsin is very rapid in Stage 1 at 23°C (fig. 5). Delaying the addition of the trypsin inhibitor LBTI at intervals beyond 1 minute does not add to the activation process, as deduced from the hourly rate of angiotensin generation in Stage 2 at 37°C. Thus, essentially all the activation at a given concentration of trypsin has been completed within 1 minute of adding trypsin in Stage 1. This activation is expressed, but not further amplified, in Stage 2.

In contrast, the length of preincubation of dog plasma with trypsin (Stage 1) greatly influences the subsequent PRA values in Stage 2. Specifically, incubation with trypsin for 5 minutes (Stage 1) results in a subsequent hourly PRA of 32 ng, while a Stage 1 incubation of 30 minutes almost doubles the subsequent hourly PRA to a value of 55 ng (fig. 5). Also, the activating effect of trypsin is not restricted to Stage 1. Its action continues during Stage 2, and is not preventable by the inhibitors LBTI, SBTI, benzamidine, and polybrene (Results — "inhibitor cocktail"). Since both trypsin and kallikrein would have been blocked by these inhibitors, it follows that some other enzyme(s) was activating prorenin. In other words, trypsin had initiated a cascade effect, which continued even after trypsin or trypsin-generated kallikrein (from prekallikrein) had ceased to act directly. One or more different enzymes, not entirely inhibited by LBTI or the cocktail, were continuing to activate prorenin.

The nontryptic enzyme(s) responsible for ongoing activation of prorenin is obviously potent, and once formed, apparently resistant to the endogenous protease inhibitors of normal plasma. Aliquots as small as 50 μl of posttrypsin plasma incorporated into 300 μl of normal plasma provoked a marked increase in PRA (fig. 8). The greatest increase in PRA was provoked by the aliquot of transferred plasma that had been previously exposed to trypsin for the longest time (fig. 8, right bar). In other words, longer exposure to trypsin results in an increased formation of the prorenin activating enzyme(s) or convertase(s), which is therefore transferred in greater concentration to the normal plasma, causing it to have a higher PRA. We found that the "convertase(s)" is denatured by heat, i.e., boiling for 10 minutes, implicating an enzymic system.

The identity of the posttryptic "prorenin convertase" is unknown. Enzymes of the coagulation and fibrinolytic cascades may be involved. However, autocatalysis by renin itself in a manner analogous to another acid protease, i.e., pepsin acting on pepsinogen, cannot be ruled out. High renin concentrations are present in the reaction vessel; the enzyme is operative at the pH levels favoring renin, and is inhibited by pepstatin. But there may also be other activators. Barrett et al. have suggested a prorenin activator in rat plasma that is neither a serine protease nor renin. They showed that, after acid dialysis to pH 1.5 while renin and renin substrate were inactivated, an "acid-stable factor" retained activity and, when the dialysate was added to normal rat plasma at pH 7.4, it activated prorenin. Thus, even if renin itself is a prorenin activator, some other activator(s) must also be considered for rat, and probably also dog plasma.

In conclusion, we have shown that there is a large prorenin component in dog plasma that can be activated by trypsin, but not by cold alone. The activation by trypsin does not appear to be direct, but is mediated by some other agent(s). Despite differences between the plasma prorenin-renin systems of dog and humans, our study suggests that the dog can be used as a model for studies of prorenin-renin. In addition, the distinctive of the dog prorenin-renin system can be exploited to define mechanisms of activation, which are obviously more complex and species-specific than previously expected.

References
35. Herriot RM: Isolation, crystallization, and properties of pepsin inhibitor. J Gen Physiol 24: 325, 1941
Plasma prorenin in humans and dogs. Species differences and further evidence of a systemic activation cascade.
E A Wilczynski and D H Osmond

doi: 10.1161/01.HYP.5.3.277

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1983 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/5/3/277

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/