Chapter 2
The Kallikrein–Kinin Pathways in Hypertension and Diabetes

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Abstract  Cardiovascular diseases are the most common causes of mortality worldwide. Hypertension and diabetes are the two major risk factors in the development of cardiac hypertrophy, ischemic heart disease, and cardiac failure. In Kuwait, high rate of prevalence of hypertension and diabetes has been documented. Previous studies have indicated altered activities of the BK-generating components in hypertension and diabetes. Bradykinin is pharmacologically active polypeptide that can promote both cardiovascular and renal function, for example, vasodilation, natriuresis, diuresis, and release of nitric oxide (NO). In addition, B2 kinin receptors are present in the cardiac endothelial cells which may enhance the biosynthesis and release of NO. It has been demonstrated that reduced urinary (renal) kallikrein levels may be associated with the development of high blood pressure in humans and spontaneously hypertensive and diabetic rats. The BK may produce its pharmacological effects via NO and cyclic GMP release. Furthermore, it is established that the BK has cardioprotective actions in myocardial ischemia and can prevent left ventricular hypertrophy. Also, transgenic mice carrying tissue kallikrein gene and overexpressing tissue kallikrein had reduced blood pressure. NO synthase and renal tissue kallikrein are both involved in blood pressure regulation. The ability of kallikrein gene delivery and the use of kinin B2 receptor agonists to produce a wide spectrum of beneficial effects make it a powerful candidate in treating hypertension, cardiovascular, and renal diseases. Strategies that activate kinin receptors might be applicable to the treatment of cardiovascular disease. Increased plasma prekallikrein levels in diabetic patients may serve as an indicator of developing hypertension and renal damage. Also high plasma and urine concentrations of tissue kallikrein may cause higher glucose levels in the blood.

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2.1 Introduction

The blood pressure (BP)-lowering effect of the kallikrein–kinin system (KKS) has been described for more than six decades (Frey 1926). It is now widely believed that the KKS is involved in controlling BP. Exogenously administered kinins cause hypotension, natriuresis, arterial vasodilatation, increased renal blood flow, and fall in peripheral resistance (de Freitas et al. 1964; Willis et al. 1969; Adetuyibi and Mills 1972; Nasjletti et al. 1978; Mills 1982). Thus, it is conceivable that reduced activity of the KKS could result in sodium retention, arterial vasoconstriction, raised peripheral resistance, increased vascular or plasma volume, and production of high BP (hypertension). Hence, reduced kinin generation in the blood stream is thought to play an important role in the development of hypertension. In this regard, it has been demonstrated that the urinary kallikrein excretion is diminished in clinical and experimental hypertension (Margolius et al. 1971; Adetuyibi and Mills 1972; Croxatto and Martin 1970; Lechi et al. 1978). Furthermore, kallikrein excretion in the urine is viewed as an index of the activity of KKS in the renal system. This review is intended to discuss the significant role of KKS in hypertension and diabetes.
2.2 The Components of the Kallikrein–Kinin System

Vasoactive polypeptides, kinins, are released in the blood stream from precursors, kininogens, by the enzymatic actions of a group of serine proteases known as kallikreins (Fig. 2.1). Kinins are straight-chain peptides which resemble bradykinin (BK) \((\text{Arg}^{1}\text{-Pro}^{2}\text{-Pro}^{3}\text{-Gly}^{4}\text{-Phe}^{5}\text{-Ser}^{6}\text{-Pro}^{7}\text{-Phe}^{8}\text{-Arg}^{9})\) in structure and in pharmacological actions (Sharma and Buchanan 1979; Schachter 1980).

2.2.1 Kininogens

Two kallikrein substrates, low molecular weight (LMW) and high molecular weight (HMW) kininogens, have been isolated from bovine plasma (Komiya et al. 1974). They differ in molecular weights (HMW-76,000; LMW-48,000) and in their susceptibility to plasma and tissue kallikreins. The HMW kininogen is the main
substrate for plasma kallikrein, and LMW kininogen is the most suitable substrate for tissue kallikrein. Two kininogens with different molecular weights (HMW-120000; LMW-78000) have also been isolated from human plasma (Jacobsen 1966; Nagasawa and Nakayasu 1975). The presence of a third form of human kininogen of about 200,000 daltons has been demonstrated (Pierce and Guimaraes 1975).

The deficiency of HMW kininogen appears to be the source of the multiple defects such as repaired clotting, kinin release, and surface-activated fibrinolysis in plasma. The HMW kininogen is also known as a “Fitzgerald factor,” because its absence was found first in the Fitzgerald family (Saito et al. 1974; Colman et al. 1975; Wuepper et al. 1975; Lacombe et al. 1975). Saito et al. (1975) have reported that purified preparations of “Fitzgerald factor” isolated from normal plasma contain HMW kininogen, however, the plasma from Mr. Fitzgerald contained about 50% of the amount of kininogen found in normal plasma which is of the LMW form. It seems, therefore, HMW is essential not only in the kinin formation, but also in the regulation of blood coagulation pathway. This defect has been reversed by the treatment with purified HMW kininogen (Wuepper et al. 1975; Lacombe et al. 1975; Colman et al. 1975). Further, Hageman factor (HF) activates prekallikrein (inactive) to kallikrein (active), which is dependent on HMW kininogen. Thus, HMW could serve as a cofactor in the initiation of blood coagulation and the inactivation of kinin generation (Kaplan et al. 1981; Lynch and Shariat-Madar 2012).

2.2.2 Kallikreins

Kinin-forming enzymes, kallikreins, have been divided into two groups; plasma and tissue or glandular. They differ mainly in molecular weight, biological functions, physiochemical and immunological properties, and on the basis of their distribution in the body.

2.2.2.1 Plasma Kallikrein

The plasma kallikrein is present in the circulation in an inactive form known as prekallikrein or Fletcher factor. It has been described that a plasma designated Fletcher trait deficiency possessed a reduced rate of surface-mediated coagulation (prolonged partial thromboplastin time) which approached normal when the incubation time with kaolin is increased. (Hathaway and Alsever 1970). Prekallikrein is activated by HF (Kaplan and Austen 1971). Plasma kallikrein has also been shown to activate inactivated HF to active HF in the fluid phase (Cochrane et al. 1973). Kaplan et al. (1977) suggested the conversion of a small amount of prekallikrein to kallikrein by activated HF is necessary prior to feedback activation of HF. This finding has further demonstrated that plasma kallikrein does not only liberate kinins, but it is also required for the regulation of normal circulatory homeostasis. A genetic defect resulting in prolonged blood clotting time (Fletcher disease) has been corrected successfully with plasma prekallikrein (Wuepper 1973).
2.2.2.2 Tissue Kallikrein

Tissue kallikreins are present in the kidney, pancreas, intestine, salivary gland, bronchoalveolar lavage fluid of asthmatic patients, and synovial tissue (Nustad et al. 1975; Fiedler et al. 1970; Zeitlin 1972; Bhoola et al. 1965; Christiansen et al. 1987; Sharma et al. 1983a). However, the presence of tissue kallikreins in the plasma has also been reported (Nustad et al. 1979; Rabito et al. 1979; Lawton et al. 1981; Rabito et al. 1982). The value of these observations remains unclear. Although, the release of submandibular gland kallikrein into the circulation has been indicated after sympathetic nervous system stimulation, which may cause reactive vasodilation in the rat submandibular gland (Rabito et al. 1983). Tissue kallikreins have similar physiochemical properties, and these enzymes are immunologically identical within the same species (Fiedler 1979); though, the factors which determine tissue kallikrein secretion are not well defined and could exhibit tissue as well as species differences. It has been reported that the salivary secretion of kallikrein in the rat is regulated by the sympathetic and parasympathetic nervous systems, although the stimulation of sympathetic produces an increased secretion of kallikrein than the stimulation of parasympathetic system (Beilenson et al. 1968; Orstavik and Gautvik 1977; Rabito et al. 1983). On the other hand, α-adrenergic stimulation appeared to inhibit urinary kallikrein excretion from the kidney of the dog and the rat (Olsen 1980, 1982). In the kidney, tissue kallikrein is synthesized in the distal tubular cells (Orstavik et al. 1976). It has been suggested that part of the kallikrein excreted in the urine could be of plasma origin (Fink et al. 1980), although the urinary kallikrein appears to be secreted in the distal segments of the nephron (Scicli et al. 1976). The urinary excretion of kallikrein reflects the activity of the enzyme in the rat kidney (Marin-Grez et al. 1982). The renal kallikrein has been suggested to regulate BP and its possible involvement in the physiopathology of hypertension (Carretero and Scicli 1981; Ostravik 1981; Sharma 2013; Sharma and Fernandez 1982). Furthermore, tissue kallikreins are implicated in a variety of physiological actions, including salt and water excretion, and activation of both striopeptigen and prorenin, as well as release of lysyl-bradykinin (kallidin) from kininogens. Several agents that non-specifically block serine proteases, including kallikreins, have been reviewed by Vogel (1979). A recent study has provided new data on the specificity of tissue kallikreins and its involvement in enkephalin biosynthesis (Prado et al. 1983).

2.2.3 Kininases

When a kinin is incubated with blood or with a tissue homogenate, it is rapidly cleaved to inactive peptides. Therefore, kinin-inactivating enzymes are collectively known as kininases. Kininase I (carboxypeptidase N) is present in the plasma of man and animals that cleaves basic C-terminal amino acids, including Arg9 of BK (Erdos and Sloane 1962). This enzyme has been purified from human
plasma (Erdos et al. 1967; Oshima et al. 1974). Whereas Erdos and Yang (1966, 1967) first detected an enzyme in the kidney cortex and subsequently in the plasma (Yang and Erdos 1967) which inactivates BK by cleaving the C-terminal of the nonapeptide. This kininase was named as kininase II (peptidyl dipeptide hydrolase) or angiotensin I-converting enzyme (ACE). At present, kininase II (ACE) inhibitors are clinically more important in the treatment of hypertension.

2.3 Interactions with Other Endogenous Agents

2.3.1 Renin–Angiotensin System

It has been suggested that the rennin–angiotensin system (RAS) and KKS act as opposing forces in the regulation of BP. Under certain situations, the inhibition of a vasodilator system (KKS) occurring during the activation of a vasoconstrictor system (RAS) might function together in control or increase of BP. The inactive renin is activated in vitro by plasma and tissue kallikreins (Sealey et al. 1978; Derkx et al. 1979). Although it has been reported that the inactive renin separated from active renin could not be activated by tissue kallikrein, however, after acid treatment, the inactive renin was activated in the presence of tissue kallikrein (Yokosawa et al. 1979). This finding was confirmed when Hiwada et al. (1983) reported that tissue kallikrein does not directly activate inactive renin but participates in the activation process of inactive renin. An increased urinary kallikrein excretion has been observed in dogs after intra-arterial infusions of angiotensin II (MacFarlane et al. 1974). Mills et al. (1976) suggested that under situations of raised renin–angiotensin production, the renal KKS might also be activated to antagonize raised vasoconstriction of renal vasculatures. Indeed, kinase II (ACE) is known for the conversion of angiotensin I into the potent vasoconstrictor angiotensin II, as well as responsible for the biodegradation of BK, a potent vasodilator agent (Erdos and Skidgel 1985). The multihormonal regulation of renal kallikrein and its possible interactions with the renin–angiotensin–aldosterone system, the corticotropin–glucocorticoid system, antidiuretic hormone, catecholamine, and prostaglandins (PGs) have been discussed in an excellent review by Marin-Grez (1982). However, there was no correlation between renal tissue kallikrein and plasma renin activity in either two-kidney or one-kidney renal hypertension (Carretero et al. 1974).

2.3.2 Prostaglandins

PGE possesses a wide range of pharmacological actions. It is synthesized by vascular tissue, and participates in regulation of vascular tone, and also acts as a local vasoactive agent in the kidney through influencing local blood flow, salt and
water excretion (Bunting et al. 1976; Gryglewski et al. 1976; Vane and McGriff 1975). Nonetheless, there is considerable evidence to suggest the pharmacological interactions between BK and PGs. BK-mediated production of PGs has been observed in a variety of tissue such as the kidney (McGiff et al. 1972), spleen (Ferreira et al. 1971), and the lung (Palmer et al. 1973). Furthermore, intrarenal arterial infusions of BK into the canine kidney caused release of PGE-like agents. In the rat, it has been reported that administration of tissue kallikrein inhibitor Trasylol, produced reduction in PGE, and kallikrein concentration in the urine (Nasjletti et al. 1978). In this way, alterations in KKS might have profound effects on PGs concentrations in the renal circulation (Colina-Chourio et al. 1976), therefore, PGs could contribute to the actions of BK on salt and water excretion (McGiff et al. 1975). Intraperitoneal administration of PGE$_2$ can produce reduction in plasma kininogen levels in the rat (Sharma and Zeitlin 1982). It is suggested that PGE$_2$, but not PGF$_2$, might produce kinins by activating plasma prekallikrein to kallikrein (Sharma and Zeitlin 1982). Also, the duration of hypotensive action of BK in Dahl rats is inhibited by PGs synthetase inhibitor such as indomethacin (Sharma et al. 1984a). This reduction in the duration of the hypotensive effect of BK is the result from an inhibition of the cyclo-oxygenase system in the Dahl rats. It has also been reported that BK activates a phospholipase (Hong and Levine 1976) which releases arachidonic acid and lead to increased synthesis of PGs (Damas and Bourdon 1974).

In patients with Bartter’s Syndrome, there is high plasma renin, hyperaldosteronism, hypokalemic alkalosis, and juxtaglomerular hyperplasia, however, in spite of the raised plasma renin, the BP remains normal (Bartter et al. 1962). Enhanced renal kallikrein and PG have been implicated in the etiology of this syndrome. These suggestions are supported by the findings of raised PGE$_2$ and kallikrein concentrations in the urine (Gill et al. 1976; Vinci et al. 1976; Lechi et al. 1976). In patients with Bartter’s syndrome, indomethacin and other cyclo-oxygenase inhibitors therapy caused a remarkable reduction in the plasma renin concentrations and aldosterone, PGE$_2$ and kallikreins levels in the urine and also corrected the hypokalemic alkalosis without altering the BP (Gill et al. 1976; Halushka et al. 1977). These observations strongly suggest that PGE is involved in the renal regulation of renin and kallikrein systems. Thus, reduction in angiotensin II might cause fall in the aldosterone levels to normal so that hypokalemia could be corrected (Mills 1979). However, Strand and Gilmore reported that PGs do not mediate the renal effects of BK in the dog.

### 2.3.3 Vasopressin

There are several reports to suggest a complex interaction between vasopressin (VP) and KKS. Kinins are powerful antagonists of the hydro-osmotic effect of VP in the toad urinary bladder (Furtado 1981; Carvounis et al. 1981) and water permeability
in the renal medulla. These investigators also observed that this action of kinin was antagonized by antidiuretic hormone. Kinins are known as potent activators of PG synthesis in the kidney (McGiff et al. 1972). Further, it has been reported that PGs interfere with the hydroosmotic actions of VP (Fejes-Toth et al. 1977). VP administration can cause PGE release in the rabbit kidney (Miller et al. 1986a), which might reduce the response of the collecting duct to VP (Zusman and Keiser 1977). Fejes-Toth and Fejes-Totah (1986) provided indirect evidence to support the notion that arginine-vasopressin might activate renal KKS, but the mechanism of action and its implication in hypertension remains to be determined. Hence, it is possible to suggest that interactions between the renal KKS and renal PGs might contribute to the control of renal blood flow, and salt and water homeostasis. Recently, it has been shown that arachidonic acid-stimulating PG release takes place in pre-glomerular blood vessels and hence 6-keto-PGE1α, whereas arginine-vasopressin (AVP) activates PGE2 release from post-glomerular sites, an action shared with angiotensin II (Miller et al. 1986a, b). It indicates that arachidonic acid and AVP differ in profile of PG release in the renal vascular compartments. Interactions between the KKS, PGs, and VP might have greater physiological importance in the control and counterbalance of antidiuretic hormone, however, such evidence needs to be established. In this regard, Fejes-Toth et al. (1982) and Fejes-Toth and Fejes-Totah (1986) reported that VP is a potent activator of kallikrein when given during water diuresis and the kinin released may antagonize the effect of VP thus, completing a full negative feedback system.

2.4 Pathophysiological Roles of Bradykinin System in Hypertension and Diabetes

2.4.1 Clinical Hypertension

Hypertension is a major risk factor in the development of cardiovascular diseases, such as coronary heart disease, congestive heart failure, and peripheral vascular and renal diseases. There is ample evidence documenting the role of BK in the pathogenesis of hypertension (Sharma 2009a; Katori and Majima 2006). The pharmacological actions of BK in regulation of systemic BP are vasodilation in most areas of circulation, reduction in total peripheral vascular resistance, and regulation of sodium excretion from the kidney (de Freitas et al. 1964). When BK is injected into the renal artery, it causes diuresis and natriuresis by increasing renal blood flow (Webster and Gilmore 1964). These actions of BK have been attributed to PGs release in the renal circulation (McGiff et al. 1975). In 1934, Elliot and Nuzum had already noticed that hypertensive patients without clinically apparent renal disease have significantly low levels of urinary kallikrein than normotensive subjects (Elliot and Nuzum 1934). This abnormality in human hypertension was not confirmed until 1971.
The role of KKS in hypertension was established by Margolius and co-investigators (Margolius et al. 1971, 1972, 1974) with the observations that urinary kallikrein excretion is significantly reduced in hypertensive patients and hypertensive rats. This led to the suggestion that reduced urinary kallikrein excretion might result from a reduction in kinin generation in hypertensive situations. Kallikrein excretion in white hypertensive men was lower than that in white normotensives during normal sodium intake, but was not different from that in black hypertensives and black control subjects under the same conditions. The kallikrein levels in the urine of normotensive black subjects are significantly lower than those in normal white subjects. All groups have greater urinary kallikrein activity on a low-sodium diet versus an unrestricted sodium intake, but the increase in black hypertensives is small. Plasma renin activity shows similar increments after sodium restriction in all groups. Similar results on reduced excretion of urinary kallikrein in black subjects were obtained (Carretero et al. 1978). Plasma kinins in clinical hypertension is known to be modulated by loss of sodium. These findings strongly support the view that sodium intake can modulate the kinin system.

Furthermore, patients with malignant essential hypertension excrete less urinary kallikrein than those with non-malignant essential hypertension and normotensive control subjects (Hilme et al. 1992). Some studies have reported that white patients with uncomplicated essential hypertension show normal kallikrein excretion rates with normal plasma renin activity and aldosterone. Only hypertensives over 40 years old excrete a significantly lower excretion of urinary kallikrein (Koolen et al. 1984). Moreover, recently in Brazilian study showed lower urinary kallikrein activity in hypertensive patients than control subjects (Belo et al. 2009). On the other hand, it is noted that hormone replacement therapy caused a significant rise in urinary kallikrein levels that might have cardioprotective effect (Farag et al. 2003).

It has been suggested that the race and sodium intake in hypertension have greater influence upon kallikrein excretion (Zinner et al. 1976; Levy et al. 1977; Azizi et al. 2008). These investigators evaluated urinary kallikrein levels in large populations of hypertensive cases and their families. The result showed that whites excrete more kallikrein than blacks and white hypertensives excrete less kallikrein than white normotensive individuals. All test groups had higher kallikrein excretion when kept on low-sodium intake. Black hypertensives excreted less kallikrein than black normotensives during sodium reduction. Furthermore, families with reduced kallikrein excretion had higher BP than those with increased urinary kallikrein excretion. This could suggest a genetic defect in the renal kallikrein and/or the presence of higher amounts of tissue kallikrein inhibitor in certain races. An altered frequency of a promoter polymorphism of kinin B2 receptor (B2R) gene in hypertensive African–Americans has been documented well (Gainer et al. 2000). Also, pregnancy-induced hypertension has been suggested to be due to decreased kidney kallikrein excretion, which could be lacking of BP-lowering factors in pregnancy to cause rise in BP (Karlberg and Wichman 1984). The identification of a subset of subjects with genetically reduced kallikrein activity as a result of an
amino acid mutation could facilitate analysis of the role of the KKS in renal and vascular diseases (Slim et al. 2002).

Kallikrein excretion was decreased in hypertensive patients with mild renal insufficiency (Holland et al. 1980) Although no significant difference in the urinary kallikrein excretion of patients with low-renin essential hypertension was found, hypertensive patients with mild renal insufficiency showed reduced urinary kallikrein excretion (Holland et al. 1980). Patients with reduced glomerular filtration rates showed markedly decreased urinary kallikrein excretion, like those with hypertension (Mitai et al. 1978). Renal parenchymal diseases with hypertension, such as chronic glomerulonephritis, are associated with diminished kallikrein activity (Holland et al. 1980).

However, recent studies suggest a strong influence of urinary kallikrein excretion on the salt sensitivity of BP in normotensive patients. In a randomized crossover double-blind study, the urinary excretion of active kallikrein was significantly lower in salt-sensitive hypertensives than in salt-resistant hypertensive patients and it showed an inverse correlation with plasma atrial natriuretic peptide levels. Thus, at least some of the hypertensive patients excrete lower levels of kallikrein without reduced renal function.

Research on the systemic changes in the kallikrein has provided further insight regarding the mechanisms of various hypertensive conditions. In this connection, it is known that kininogen levels and kinin-forming factors are reduced in essential and malignant hypertension (Almeida et al. 1981; Sharma and Zeitlin 1981). It may be that a deficiency of plasma HMWK due to a decrease in liver synthesis (which decreases kinin production) occurs in an individual who develops hypertension after mild exercise (James and Donaldson 1981). It is proposed that a deficiency in BK might be a significant factor in the pathophysiology of hypertension. In this regard, it is suggested that the role of renal BK is to excrete the excess of sodium. Therefore, a reduction in the generation of renal BK may be the cause in the development of hypertension as a result of the accumulation of sodium in the body (Katori and Majima 2006). Thus, the development of a compound having renal kallikrein-like activity may serve the purpose of excreting excessive sodium from the kidney in the treatment of hypertension.

### 2.4.2 Experimental Hypertension

Rats with renovascular hypertension have decreased kallikrein levels both in renal tissue and urine. In two kidney-one clip Goldblatt hypertensive rats, the urinary kallikrein level was low in the urine from stenotic kidney, whereas that of the contra lateral kidney was normal. In Dahl salt-sensitive rats fed a normal sodium diet (0.45 % NaCl), the urinary kallikrein level determined by the kinin-generating activity is lower than the level determined by direct radioimmunoassay for the enzymic protein. The level of urinary protein is higher in these rats. The lower level of kallikrein may be due to inhibitors leaking from the plasma. The reduced
levels of kallikrein in hypertension should be distinguished from those due to impaired renal function.

It has been demonstrated that transgenic mice overexpressing renal tissue kallikrein were hypotensive and that administration of aprotinin, a tissue kallikrein inhibitor, restored the BP of the transgenic mice. We have shown the suppression of hypotensive responses of ACEIs by aprotinin in spontaneously hypertensive rats (SHR). These findings highlight a role of tissue kallikrein in the regulation of BP. Recently, it has been proposed that tissue kallikrein gene delivery into various hypertensive models exhibits protection, such as reduction in high BP, attenuation of cardiac hypertrophy, inhibition of renal damage, and stenosis (Chao and Chao 2005; Chao et al. 1998, 2006). This may indicate the future therapeutics aspect of kallikrein gene therapy for cardiovascular and renal pathology. Tissue kallikrein can have antihypertensive function in physiological states where sodium retention can trigger high BP (Potier et al. 2013).

ACEIs are currently used in the treatment of both clinical and experimental hypertension (Antonaccio 1982; Silberbauer et al. 1982; Sharma et al. 1983a, b, 1984a, b, c). Kininase II inhibitors could lower BP by inhibiting the biodegradation of kinin as well as blocking the formation of angiotensin II (AgII). A calcium-channel blocker, nifedipine, used in the treatment of patients with essential hypertension can normalize the reduced urinary kallikrein excretion (Edery et al. 1981). Smith et al. have suggested that women with reduced activity of the renal BK may be at increased risk of developing pregnancy-induced hypertension. A previous study has demonstrated that urinary kallikrein excretion was found to be diminished in family members at risk of hereditary hypertension and that urinary kallikrein may be one of the major genetic markers associated with family history of hypertension (Kailasam et al. 1998).

The earlier studies have clearly indicated that there is influence of race, diet, sodium, and potassium intake on the BK-producing components. However, there has been no such study on the BK system and its related mediator (NO) in the Arab population with special interest to Kuwaiti population. Hence, such an investigation will highlight the significance of the role of BK system and its interacting mediator (NO) in the pathophysiology of hypertension and diabetes in Kuwaiti patients with and without treatment. Also, the beneficial effects of the treatment could be mediated by alterations in the BK system and NO.

Left ventricular hypertrophy (LVH) is regarded as an independent risk factor in hypertensive patients in inducing cardiac abnormalities. BK can counter the development of LVH in rats with hypertension produced by aortic banding (Linz et al. 1993; Madeddu et al. 2007). This antihypertrophic effect of BK was abolished by the B2R antagonist treatment as well as by NO synthetase inhibitor. Thus, the BK has a role in protecting the heart against developing LVH by releasing NO in this model of hypertension induced by aortic banding. In this regard, we have for the first time demonstrated that the lack of the cardiac KKS could be responsible for the induction of LVH in SHR and SHR with diabetes (Sharma et al. 1998, 1999). It is suggested that the reduced cardiac tissue kallikrein and cardiac kininogen may be responsible for reduced BK generation in the heart. Therefore, deficient components
of the BK in the heart may be responsible for inducing excessive hypertrophy and myocardial dysfunction in cases of hypertension. It is highly desirable to develop stable compounds of BK to evaluate their efficacy and potency in cases of cardiac failure, cardiac ischemia, and hypertension (Sharma et al. 1999).

It is the generally accepted view that the BK-induced BP-lowering effect is mediated by the B2R, but B1 might also be involved under special situations (Regoli 1984). It has been demonstrated that a B2R antagonist (B5630) can generally abolish the hypotensive effects of BK as well as captopril, an ACEI (Sharma 2009b). This led to the proposal that the hypotensive action of ACE inhibitors might be due to the activation of B2R (Sharma 2009b). The accumulation of BK after treatment with ACEIs with subsequent release of NO, PGs, and prostaglandin I2 (PGI2) could account for additional mediators released in the process of antihypertensive action of these drugs in hypertensive patients.

2.4.3 Diabetes

Diabetes is a major risk factor in the development of cardiovascular and renal complications. Previous studies have indicated conflicting results of the BK-forming components (Leeb-Lundberg et al. 2005) in diabetic patients and experimental animals. High prevalence rates (20–25 %) of type 2 diabetes have been documented in Kuwaiti population (Abdella et al. 1998; Al-Shoumer et al. 2008). Type 2 diabetes can lead to hypertension, renal, and cardiac complications, resulting in high rates of mortality worldwide and in Kuwait as well. BK, a pharmacologically active polypeptide, is one of the kinins which is released in the tissues and body fluids as a result of enzymatic action of kallikreins on kininogens. The two types of kallikrein are tissue kallikrein and plasma kallikrein. Plasma kallikrein is also present in inactive form known as prekallikrein, which can be activated into kallikrein. Tissue kallikrein is mainly expressed in the kidney (urine), glandular tissue, vasculature (Sharma and Narayanan 2011) heart, and brain. It preferentially acts on LMW kininogen substrate to release lysyl-BK. Tissue kallikrein has also been reported to be present in plasma (Rabito et al. 1982; Yayami et al. 2003). Plasma kallikrein preferentially acts on HMW kininogen substrate to release BK. BK promotes both cardiovascular and renal functions, for example, vasodilation, natriuresis and diuresis(Katori and Majima 2006; Sharma et al. 1998); BK is rapidly (<15 s) inactivated by circulating kinases (Sharma et al. 1996); BK acts on B1 receptor (B1R) and B2R (Jaffa et al. 2003) to elicit physiological and pharmacological actions. It has been shown previously that type 1 diabetic patients are at a risk of developing nephropathy with increased renal tissue kallikrein and BK levels (Harvey et al. 1990). In addition, raised plasma prekallikrein levels in type 1 diabetes has been considered as a risk marker for hypertension and nephropathy (Jaffa et al. 1995). This has not yet been reported in type 2 diabetic patients. However, in diabetic rats, it has been shown that moderate hyperglycemia, in association with increased urinary kallikrein excretion, can result in reduced
renal vascular resistance (RVR) and increased both renal plasma flow (RPF) and glomerular filtration rate (GFR) (Harvey et al. 1990; Jaffa et al. 1995). The treatment with aprotinin, a kallikrein inhibitor, to these rats increased the RVR and reduced the GFR and RPF (Harvey et al. 1990; Jaffa et al. 1995). In diabetic patients, urinary and plasma tissue kallikrein concentrations were significantly increased. In addition, plasma prekallikrein levels were also reduced in diabetic patients when compared with healthy subjects. This is the first investigation among Kuwaiti Arab patients with type 2 diabetes, showing abnormal activities in the BK-forming system. High levels of plasma prekallikrein may be a risk factor for developing high BP as well as nephropathy. The urinary and plasma tissue kallikrein concentrations were higher in diabetic patients that could indicate the hyperactivities of these components, which may result in increased level of plasma glucose to induce diabetes. Furthermore, the urinary kininogen levels were reduced in diabetic patients. These alterations might reflect the utilization of urinary kininogen to form BK, a potent inflammatory agent. However, this hypothesis needs further investigation.

Several investigators (Jaffa et al. 1995; Harvey et al. 1990) have reported alterations in the renal KKS in the diabetic state. Insulin-treated moderately hyperglycemic diabetic rats and patients with diabetes mellitus have been reported to show increased urinary kallikrein and BK excretion (Jaffa et al. 1995). These findings suggest that alterations in the kinin-forming components may be the indicator of vascular disease in type 1 diabetics. The renal hyperfiltration in diabetic rats was reduced after pretreatment with aprotinin, a tissue kallikrein inhibitor, suggesting a role of KKS in diabetic state of increased glomerular hemodynamics. In addition, Vieira et al. (1994) demonstrated the renal conversion of T-kinin (present in the rats) to BK. The conversion of T-kinin, which is the main kinin in inflammation in rats, could be an important alternative pathway for the generation of renal BK in diabetic rats. On the other hand, the metabolism of BK might be impaired and it has to be shown whether changes in the activity of kininases could lead to an increased urinary BK excretion under diabetic conditions. In previous studies, it has been observed the reduction in cardiac and plasma kallikrein and kininogen concentrations in hypertensive and diabetic rats (Sharma et al. 1998). These studies suggested that the development of LVH and high BP in these diabetic rats could be the reflection of hypo-activity of the KKS. These research findings were indeed supported by the fact that the reduced synthesis of the myocardial tissue kallikrein implies a reduced capacity to generate BK in diabetic rats (Jaffa et al. 2003). It can be postulated therefore that alterations in the KKS may contribute to the cardiac dysfunction in diabetes mellitus in human patients. Furthermore, it is suggested that the treatment with the KKS components in diabetic conditions may reverse the myocardial abnormalities observed in diabetic patients. Recently, it has been reported that high plasma prekallikrein activity may serve as a marker for the diabetic hypertensive nephropathy (Jaffa et al. 2003), which may be the marker of vascular disease in diabetic patients. It has been recently pointed out that cardioprotective effects on the KKS in the
diabetic heart suggest that the stimulation of the KKS might open new avenues for the treatment of diabetic cardiopathy due to down regulation of kinins-inactivating enzymes (Spillmann et al. 2006; Koch et al. 2003). Also, BK2 receptor activation may contribute to the development of diabetic nephropathy (Tan et al. 2005). On the other hand, kallikrein gene delivery improves serum glucose, lipid profile, and cardiac function in experimental diabetic rats (Montanari et al. 2005). Recently, it has been suggested that BK system may be a therapeutic target in preventing and treating diabetic nephropathy (Riad et al. 2007). Also, the suppressed KKS within podocytes under diabetic condition is associated with podocyte apoptosis, suggesting that BK may be beneficial in preventing podocyte loss in diabetic nephropathy (Kwak et al. 2011). Recently, it has been documented that urinary and plasma tissue kallikrein levels were higher in type 2 diabetic patients than in healthy controls (Campbell et al. 2010; Sharma et al. 2013). This has been suggested to cause increased level of glucose in the circulation by blocking the glucose utilization. In addition, Liu and Feener (2013) has proposed that plasma KKS are potential therapeutic targets for diabetic retinopathy (macular edema) and nephropathy (Tomita et al. 2012; Liu and Feener 2013).

2.5 Tissue Kallikrein and Kininase II Inhibitors as Antihypertensive Agents

The kallikrein might have a prime action in the regulation of systemic BP, because administration of tissue kallikrein to hypertensive patients can bring the BP to the normal levels. It has been shown that the pig pancreatic kallikrein therapy lowered the BP significantly and normalized their reduced urinary kallikrein excretion in patients with essential hypertension (Overlack et al. 1980, 1981). These data provide favorable evidence that the presence of subnormal activity of kinin-generating system might be a prominent predisposing cause in the genesis of hypertension. Since the antihypertensive mechanism(s) of pancreatic kallikrein treatment remains unknown, the possibility exists that tissue kallikrein may have independent actions in regulating arterial BP. There is, however, no direct evidence in support of this hypothesis.

Kininase II (ACE) inhibitors such as captopril, enalapril, and teprotide are currently used in the treatment of both clinical and experimental hypertension (Silberbauer et al. 1982; Antonaccio 1982; Sharma et al. 1983b, 1984b; Fernandez et al. 1983a, b; Edery et al. 1981). Kininase II inhibitors might possibly lower BP by inhibiting the biodegradation of kinin as well as inhibiting angiotensin II formation at the renin site. Katz et al. (1980) determine the inter-relationship between the changes in plasma kinin levels and BP reduction during i.v. infusions of BK and reported that increased plasma kinin levels of 1–2 ng/ml caused a significant reduction in BP (nearly 30 mm Hg). The magnitude of the increment in plasma kinin levels was similar to that observed during the administration of kininase II inhibitor (Swartz et al. 1979). Although there are methodological difficulties on the
estimation of plasma kinin concentrations, these findings do suggest that circulating
kinin contributes to the antihypertensive effects of kininase II inhibition. Plasma
kininogen decrease has been reported in clinical condition after administration of
nonsteroidal anti-inflammatory agents (Sharma et al. 1976, 1980; Zeitlin et al.
1976, 1977). It is important to emphasize that inhibition of kininase leading to kinin
accumulation may play a major contributing role in the mechanism of hypotensive
action of teprotide, kininase II inhibitor, in humans (Edery et al. 1981). Abnor-
mality in the urinary kallikrein excretion has also been corrected after nifedipine, a
calcium-channel blocker treatment in patients with essential hypertension (Tsunoda
et al. 1986). Whereas Sharma et al. (1984c) demonstrated differential sensitivity of
Dhal salt-sensitive (DSS) hypertensive and Dhal salt-resistance (DSR) normoten-
sive rats to the hypotensive action of nifedipine. This might reflect a significantly
more important role of diminished renal kallikrein–kinin activity in DSS hyper-
tensive than DSR normotensive rats. Tissue kallikrein is documented to be involved
in the cardioprotective effect of AT1-receptor blockade in acute myocardial
ischemia in mice (Messadi-Laribi et al. 2007).

2.6 Conclusion

Reduced kinin-forming components might be responsible for the pathophysiology of
hypertension. In this regard, it is suggested that the role of renal BK is to excrete the
excess sodium. Reduction in the generation of renal BK may be the cause in the
development of hypertension as a result of accumulation of sodium in the body. Thus,
the development of a compound having renal kallikrein-like activity may serve the
purpose of excreting excessive sodium from the kidney in the treatment of hyper-
tension. Transgenic mice over expressing renal tissue kallikrein were hypotensive,
and administration of aprotinin, a tissue kallikrein inhibitor, restored the BP of
transgenic mice. Recently, it has been proposed that tissue kallikrein gene delivered
into various hypertensive models exhibits protection, such as reduction in high BP,
attenuation of cardiac hypertrophy, inhibition of renal damage, and stenosis.

Also, abnormalities in the BK system have been documented in diabetes
mellitus. It has been suggested that high levels of renal tissue kallikrein and BK
may mediate renal hyper-filtration in diabetes. In addition, higher concentration of
prekallikrein in plasma may serve as indicator for the development of hypertension
and kidney damage.

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