Original Article

Clinical Characteristics and Treatment Outcomes of Primary Aldosteronism in a Tertiary Hospital in Thailand

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Abstract

Background: Primary aldosteronism (PA) is the most common cause of endocrine hypertension, increasing cardiovascular and renal risks. This study aimed to provide comprehensive information on PA patients in Thailand, where data are limited.

Materials and Methods: A retrospective study of 127 PA patients during 2012 to 2023 from Thammasat University Hospital was conducted. Data on clinical and biochemical parameters, screening, confirmatory testing, subtype classification, and treatment outcomes were evaluated.

Results: Fifty patients (39%) had unilateral PA, 50 (39%) bilateral PA, and 27 (21%) were classified as inconclusive subtype. Mean age was 54 years, and 54% were female. All participants had hypertension, with 10% having resistant hypertension. Eighty-three percent had hypokalemia. Median plasma aldosterone concentration (PAC), direct renin concentration (DRC), and PAC/DRC ratio (ADRR) were 21.7 ng/dL, 3.7 μIU/mL, and 5.3 ng/dL: μIU/mL, respectively. The recumbent saline infusion test (RSIT) was the most common confirmatory test, with a 66% positive rate. Adrenal CT scan was performed in all cases. Ninety-two percent of patients underwent adrenal venous sampling, with a 78% success rate. Among adrenalectomy patients, 53% achieved complete clinical success and 94% achieved biochemical success. Unilateral PA showed higher PAC, ADRR, PAC-potassium ratio, and lower DRC.

Conclusions: Comprehensive PA data supports accurate diagnosis and tailored treatment. Hypokalemia is common in Thai PA patients. Unilateral PA shows a severe phenotype with distinctive hormonal profiles. For confirmatory testing, RSIT is reliable and SSIT promising. AVS, superior to CT for subtyping, is crucial for accurate subtype classification, as nearly all unilateral PA patients achieve complete biochemical remission post-adrenalectomy.

Keywords: Primary aldosteronism, Saline infusion test, Adrenal venous sampling, Adrenalectomy

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Introduction

Excessive aldosterone secretion causes primary aldosteronism (PA), which is the most common cause of endocrine hypertension. The prevalence ranges from 3.9% in stage 1 hypertension to 11.8% in stage 3 hypertension in primary care settings,[1] increases to 10% to 20% in hospital outpatients,[2, 3] and rises to 27% in patients with resistant hypertension.[4] PA also increases the risk of coronary artery disease, heart failure, stroke, atrial fibrillation, diabetes, and chronic kidney disease, compared with essential hypertension.[5] PA is associated with 1.23 times higher all-cause mortality and 1.57 times higher cardiovascular mortality relative to the general population, after adjusting for sex and age.[6]

The diagnosis and investigation of PA involve three important steps: case detection, case confirmation, and subtype classification, according to Endocrine Society guidelines.[4] Case detection is performed using the plasma aldosterone-to-renin ratio (ARR) or the plasma aldosterone-to-direct renin ratio (ADRR), which is considered the most reliable screening method for PA. Case confirmation involves several tests, with the recumbent saline infusion test (RSIT) being commonly practiced in Thailand; however, various threshold values are used to interpret these test results.[7] Lastly, subtype classification is essential for determining prognosis and treatment options. In terms of grouping, PA is categorized into unilateral and bilateral types. Unilateral adrenalectomy is the primary treatment for unilateral PA, while aldosterone antagonists, also called mineralocorticoid antagonists (MRAs), are for bilateral PA treatment.

Despite PA contributing to increased metabolic, cardiovascular, renal morbidity and mortality, as well as being the most common and curable form of endocrine hypertension, data on PA in Thailand remains relatively scarce.[8-10] Therefore, the main purpose of this study was to reveal the comprehensive clinical and biochemical characteristics, confirmatory test data, subtype classification, and treatment outcomes for PA.

Materials and Methods

Study design and population

This retrospective study collected data from a single tertiary referral center, Thammasat University Hospital, for all adult patients aged 18 years and above with confirmed PA who were followed up between 2012 and 2023. Plasma aldosterone concentration (PAC) and direct renin concentration (DRC) were quantified using a chemiluminescent immunoassay (DiaSorin Liaison® Analyzer). Prior to October 2017, renin was assessed as plasma renin activity (PRA) using the Siemens radioimmunoassay and converted to DRC by multiplying PRA values by 12. Any interfering medications were discontinued for 2-6 weeks prior to the screening test. A positive screening test was defined as a PAC level of $\geq$ 10 ng/dL and a DRC level of < 12 μIU/mL or an ADRR > 2.4 ng/dL: μIU/mL. Patients with missing key information, such as subtyping or treatment outcomes, and pregnant individuals were excluded. Data collection commenced after obtaining Thammasat University's Human Research Ethics Committee approval (MTU-EC-IM-0-258/65).

In terms of baseline, sex, age, body weight, body mass index, blood pressure, co-morbidities, antihypertensive drugs, and dosage that converted to defined daily dose (ATC/DDD index) were collected.[11] PAC, PRA, DRC, creatinine, estimated glomerular filtration rate (eGFR), electrolyte, fasting plasma glucose (FPG), and hemoglobin A1C were also collected. Additionally, the results of the 1 mg dexamethasone suppression test, with serum cortisol levels post-dexamethasone more than 1.8 μg/dL considered as autonomous cortisol secretion, were recorded.

All patients underwent at least one confirmatory test, including the recumbent saline infusion test (RSIT), supine saline infusion test (SSIT), or captopril challenge test (CCT). The testing procedures and results interpretation followed the Endocrine Society guidelines.[4] All PA patients underwent adrenal CT scans. Patients willing to undergo surgery underwent adrenal venous sampling (AVS), except for some who could proceed directly to adrenalectomy, as recommended by the Endocrine Society guidelines. The AVS was performed by three different interventionists using a continuous cosyntropin infusion protocol.

Treatment outcomes after adrenalectomy had been assessed according to the Primary Aldosteronism Surgery Outcome (PASO) consensus.[12] For patients treated with mineralocorticoid antagonists (MRAs), outcomes were evaluated based on a decrease in the ATC/DDD index of hypertensive drugs and the normalization of hypokalemia.

Definition

Unilateral PA was defined as a lateralization index (LI) ≥ 4 based on AVS results. Patients eligible for adrenalectomy without AVS as recommended by the Endocrine Society Guidelines,[4] or those who declined AVS, were also classified as unilateral PA if complete biochemical success was achieved post-adrenalectomy according to the PASO consensus. Bilateral PA was defined by an LI < 4. An inconclusive subtype was defined as any patient who could not be precisely classified as either unilateral or bilateral PA, such as those treated with MRAs without undergoing AVS or those where AVS was attempted but catheterization was unsuccessful.

Outcomes

The primary outcome was the clinical and biochemical characteristics, treatment, and outcomes of patients with PA. The secondary outcomes included the comparison of clinical and biochemical parameters between unilateral and bilateral PA.

Statistical analysis

All available PA cases in the database were included for primary outcome analysis. For secondary outcomes, the sample size calculation, based on a previous study[13] showing 27% with unilateral PA and 64% with bilateral PA, required fifty patients per group to achieve 90% power.

The statistical analysis was performed using IBM SPSS Statistics 26. Continuous variables with normally distributed data were presented as means and standard deviations (SD), while non-normally distributed data were presented as medians and interquartile ranges (IQR). Categorical variables were reported as counts and percentages. Group differences were evaluated using T-tests or Mann-Whitney U tests for continuous variables, depending on their distribution. For categorical variables, Chi-square tests or Fisher's exact tests were employed. Paired T-tests were applied to parametric data, and Cochran Q tests to non-parametric data, to compare follow-up data within the same population group. Odds ratios with 95% confidence intervals were used for univariate and multivariate analysis to identify factors distinguishing between unilateral and bilateral PA. Overall, a p value < 0.05 was considered statistically significant at the 95% confidence interval.

Results

Over 12 years, 171 PA patients were enrolled. However, 44 were excluded: 15 lost to follow-up after positive confirmation test and 29 still awaiting subtyping. Out of the 127 remaining patients, 50 (39.4%) were unilateral, 50 (39.4%) were bilateral, and 27 (21.2%) were inconclusive. Table 1 shows the baseline characteristics of the studied participants. All participants had hypertension, with a median age of 56 years and a median hypertensive duration of 6 years; 10% exhibited resistant hypertension. Eighty-three percent of individuals experienced hypokalemia, with significantly higher rates in unilateral compared to bilateral disease. The median ATC/DDD index was 3.0, without a significant difference between the groups. All co-morbidities, glycemic values, and cholesterol levels were also similar.

Table 1 Baseline characteristics of the studied patients

Clinical parameter	Total (N = 127)	Unilateral PA (N = 50)	Bilateral PA (N = 50)	Inconclusive Subtype (N = 27)	*p* value*
Female sex, n (%)	68 (53.5%)	22 (44.0%)	27 (54.0%)	19 (70.4%)	0.31
Age (years)	56 (43-64)	55 (45-61)	54 (39-63)	64 (49-72)	0.82
BMI (kg/m^2)	26.6 (23-30)	26.3 (23.8-28.6)	27.4 (24.7-30.1)	25.8 (22.2-29.0)	0.27
Duration of hypertension (years)	6 (2-11)	6 (3-10)	6 (2-12)	5 (2-15)	0.97
SBP (mmHg)	146 (16)	144 (16)	148 (17)	145 (13)	0.32
DBP (mmHg)	89 (13)	89 (13)	91 (14)	84 (11)	0.54
Resistant hypertension, n (%)	13 (10.2)	8 (16.0)	2 (4.0)	3 (11.1)	0.09
Hypokalemia, n (%)	105 (82.7)	49 (98.0)	36 (72.0)	20 (74.1)	< 0.01
Lowest serum potassium (mmol/L)	3.0 (2.7-3.3)	2.7 (2.4-2.9)	3.1 (2.9-3.5)	3.2 (3.0-3.5)	< 0.01
Co-morbidities					
Diabetes mellitus, n (%)	31 (24.4)	7 (14.0)	11 (22.0)	13 (48.1)	0.43
Dyslipidemia, n (%)	49 (38.6)	18 (36.0)	19 (38.0)	12 (44.4)	1.00
Coronary artery disease, n (%)	5 (3.9)	4 (8.0)	0	1 (3.7)	0.11
Ischemic stroke, n (%)	11 (8.7)	5 (10.0)	5 (10.0)	1 (3.7)	1.00
Hemorrhage stroke, n (%)	5 (3.9)	1 (2.0)	3 (6.0)	1 (3.7)	0.61
Atrial fibrillation, n (%)	3 (2.4)	1 (2.0)	0	2 (7.4)	1.00
Heart failure, n (%)	4 (3.1)	3 (6.0)	1 (2.0)	0	0.61
Left ventricular hypertrophy, n (%)	32 (25.2)	14 (28.0)	13 (26.0)	5 (18.5)	1.00
ATC/DDD index	3.0 (2.0-4.3)	3.3 (2.0-4.5)	3.0 (2.0-4.0)	2.7 (2.0-4.5)	0.41
Fasting plasma glucose (mg/dL)	105 (96-115)	102 (96-109)	108 (97-119)	105 (91-137)	0.07
HbA1C (%)	5.8 (5.4-6.1)	5.5 (5.3-6.0)	5.8 (5.5-6.1)	6.2 (5.6-7.3)	0.20
Total cholesterol (mg/dL)	179 (150-208)	164 (152-199)	192 (154-214)	173 (144-211)	0.06
PAC (ng/dL)	21.7 (15.0-31.6)	26.6 (18.2-46.3)	20.0 (15.6-24.8)	14.9 (10.9-28.2)	< 0.01
DRC (μIU/mL)	3.7 (1.8-7.9)	2.5 (0.9-6.8)	5.9 (2.9-9.6)	3.3 (1.9-5.0)	< 0.01
ADRR (ng/dL: μIU/mL)	5.3 (2.9-13.3)	11.2 (5.1-31.1)	3.5 (2.5-5.8)	4.9 (3.2-12.9)	< 0.01
PAC/K ratio (ng/dL: mmol/L)	7.0 (4.5-12.1)	10.8 (6.5-17.2)	6.0 (4.4-9.2)	4.5 (3.6-9.4)	< 0.01
Autonomous cortisol secretion, n (%)	10/74 (14)	3/30 (10)	5/30 (17)	2/14 (14)	0.70
Post-DEX cortisol level (μg/dL)	0.8 (0.6-1.3)	0.8 (0.5-1.0)	0.8 (0.6-1.6)	1.0 (0.8-1.6)	0.42

Data are presented as number (percent), mean (SD), or median (IQR), *p values were calculated to compare between unilateral and bilateral PA, and p value < 0.05 indicates statistically significant.

PA: primary aldosteronism; BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; ATC/DDD: total daily dose of antihypertensive agents; PAC: plasma aldosterone concentration; DRC: direct renin concentration; ADRR: aldosterone to direct renin ratio; PAC/K: plasma aldosterone concentration-to-potassium; DEX: dexamethasone.

The median serum potassium level was significantly lower in the unilateral PA group than in the bilateral PA group (2.7 vs. 3.1 mmol/L, $p < 0.01$). At the screening test, the median values for PAC, DRC, and ADRR were 21.7 ng/dL, 3.72 μIU/mL, and 5.26 ng/dL: μIU/mL, respectively. The unilateral PA group showed significantly higher PAC (26.6 vs. 20.0 ng/dL, $p < 0.01$); ADRR (11.2 vs. 3.5 ng/dL: μIU/mL, $p < 0.01$); and a lower DRC (2.5 vs. 5.9 μIU/mL, $p < 0.01$) compared to the bilateral PA group. Moreover, the median plasma aldosterone concentration-to-potassium ratio was significantly higher in the unilateral PA group (10.8 vs. 6.0 ng/dL: mmol/L, $p < 0.01$). Seventy-four patients (58%) underwent a 1-mg dexamethasone suppression test, with 14% showing autonomous cortisol secretion, with no significant difference between the two groups.

All 127 patients in the study initially underwent at least one of three different confirmatory tests: 110 patients underwent the recumbent saline infusion test (RSIT), 16 patients underwent the supine saline infusion test (SSIT), and 18 patients underwent the captopril challenge test (CCT), with some patients undergoing more than one test. Of 110 patients who underwent RSIT, 73 patients (66%) had positive results, while 37 patients (34%) had indeterminate test results. The unilateral PA group showed a significantly higher positive rate (88% vs. 61%, $p < 0.01$). The median post-RSIT PAC was significantly different between the two groups: 22.6 ng/dL for unilateral PA and 10.6 ng/dL for bilateral PA. Twenty patients out of 37 (54%) with indeterminate RSIT results underwent further confirmatory tests: 14 underwent SSIT (seated saline infusion test) and 6 underwent CCT, with all testing positive. Among the 14 patients who underwent both RSIT and SSIT, the median post-infusion PAC of SSIT was significantly higher than of RSIT (8.8 vs. 7.1 ng/dL, $p = 0.01$). Of these, 17 individuals with indeterminate results declined a second confirmatory test and were considered to have PA due to uncontrolled hypertension, elevated PAC, and persistent DRC suppression throughout the follow-up period. However, 10 of these 17 individuals presented with spontaneous hypokalemia, PAC > 20 ng/dL, and suppressed DRC, which permitted a diagnosis of PA without the need for a further confirmation test, as outlined by the Endocrine Society guidelines. Sixteen patients initially underwent SSIT, and 18 initially underwent CCT, both achieving a 100% positive rate.

Out of 127 patients, 75 (59%) had a unilateral nodule: 46 patients were in the unilateral group, 19 in the bilateral group, and 10 in the inconclusive subtype, with a median diameter of 1.4 cm, most frequently located on the left. The data on adrenal CT findings between the unilateral and bilateral PA groups are shown in Table 2. Ninety-two percent of patients in the unilateral PA group had unilateral nodules, compared to 38% in the bilateral PA group, which was smaller in size (1.2 vs. 1.5 cm, $p = 0.01$). The frequencies of bilateral nodules, unilateral thickening, and bilateral thickening were not significantly different between the two groups. Additionally, bilateral PA was more frequently associated with a normal adrenal appearance than unilateral PA ($p < 0.01$).

Table 2 Adrenal CT scans of the studied patients

	Unilateral PA (N = 50)	Bilateral PA (N = 50)	*p* value
Normal, n (%)	1 (2)	22 (44)	< 0.01
Unilateral nodule, n (%)	46 (92)	19 (38)	< 0.01
Right adrenal nodule, n (%)	17 (37)	7 (37)	1.00
Left adrenal nodule, n (%)	29 (63)	12 (63)	1.00
Size (cm)	1.5 (1.3-2.0)	1.2 (1.0-1.5)	0.01
Bilateral nodules, n (%)	2 (4)	2 (4)	1.00
Size of right adrenal nodule (cm)	1.0 (0.8-1.1)	1.5 (0.8-2.2)	0.68
Size of left adrenal nodule (cm)	1.7 (1.7-1.7)	1.5 (1.4-1.5)	0.10
Unilateral thickening, n (%)	0	3 (6)	NA
Bilateral thickening, n (%)	1 (2)	4 (8)	0.17

Data are presented as number (percent), or median (IQR), p value < 0.05 indicates statistically significant. PA: primary aldosteronism; NA: not available.

One hundred eighteen patients (93%) underwent AVS (adrenal venous sampling), with a success rate of 78%, 92 patients. This includes 42 patients in the unilateral PA group and 50 patients in the bilateral PA group. In the unilateral PA group, 29 patients (72%) were left dominant. The median maximal PAC (plasma aldosterone concentration) on AVS was higher in unilateral PA compared to bilateral PA but did not reach statistically significance. Ten patients (11%) had initial AVS results indicating bilateral aldosterone suppression (BAS), including 4 who underwent repeat AVS, resulting in bilateral PA. Five patients with a unilateral nodule and LI > 4 underwent adrenalectomy with post-operative complete biochemical success, classified as unilateral PA. One patient with resistant hypertension, hypokalemia, and a right adrenal nodule underwent repeat AVS and remained classified as BAS. Imaging revealed an accessory vein of the right adrenal gland, leading to right adrenalectomy, which also achieved complete biochemical success, classified as unilateral PA (Table 3). Additionally, 35 patients (58%) with unilateral nodules on CT scan had consistent AVS results on the same side. Six patients (67%) with bilateral adrenal nodules or thickening on CT scan had bilateral disease according to AVS results. Nearly all patients (96%) with normal adrenal CT scans were found to have bilateral disease based on AVS results. Overall concordance between adrenal CT scans and AVS results was 68% (Table 4).

Table 3 Adrenal venous sampling results of studied patients

	Unilateral PA (N = 50)	Bilateral PA (N = 50)	*p* value
Perform AVS, n (%)	49 (98)	50 (100)	0.31
Successful AVS, n (%)	42 (86)	50 (100)	< 0.01
Lateralization index	12.8 (5.3-28.2)	1.7 (1.3-2.0)	< 0.01
Contralateral index	0.2 (0.1-0.4)	1.5 (1.1-1.8)	< 0.01
Maximal PAC on AVS results (ng/dL)	3068 (1395-6363)	921 (468-1910)	< 0.01
Bilateral aldosterone suppression, n (%)	6 (14)	4 (8)	0.50
Lateralization index	9.5 (3.9-14.4)	1.6 (1.4-2.6)	0.01
Contralateral index	0.1 (0.0-0.1)	0.3 (0.2-0.4)	0.01

Data are presented as number (percent), or median (IQR), p value < 0.05 indicates statistically significant. PA: primary aldosteronism; AVS: adrenal venous sampling; PAC: plasma aldosterone concentration.

Table 4 Concordance in primary aldosteronism classification between adrenal CT scans and AVS results for patients with successful AVS.

Adrenal CT scans		AVS results				Concordance of CT scans and AVS results
		Right dominant, n	Left dominant, n	Non lateralized, n	BAS, n	
Unilateral adrenal lesions, n	60	10	26	22	2	35 (58%)
Right nodule, n	20	10	1	8	1	10 (50%)
Right thickening, n	0	0	0	0	0	-
Left nodule, n	37	0	25	11	1	25 (68%)
Left thickening, n	3	0	0	3	0	0
Bilateral adrenal lesions, n	9	0	3	6	0	6 (67%)
Bilateral nodule, n	4	0	2	2	0	2 (50%)
Bilateral thickening, n	5	0	1	4	0	4 (80%)
Normal, n	23	1	0	22	0	22 (96%)
Total, n	92	11	29	50	2	63 (68%)

Data are presented as number (percent), or median (IQR), p value < 0.05 indicates statistically significant. AVS: adrenal venous sampling; BAS: bilateral aldosterone suppression; CT: computed tomography

Of the 50 patients in the unilateral PA group, 49 underwent unilateral adrenalectomy. Post-surgery, partial clinical success and complete clinical success were observed in 43% and 53% respectively. In terms of biochemical success, 94% achieved complete biochemical success, while 6% achieved partial biochemical success. The median ATC/DDD index significantly decreased after surgery (Table 5).

All patients in the bilateral PA group were treated with spironolactone at a median dose of 25 mg per day. There was a statistically significant decrease in the median ATC/DDD index after treatment (p < 0.01) (Table 6). All patients maintained normal serum potassium levels following spironolactone treatment.

Univariate and multivariate analyses revealed that an ADRR ≥ 9.36 ng/dL: μIU/mL at screening, a post-RSIT PAC ≥ 15.15 ng/dL, and adrenal nodule size ≥ 1.35 cm were significantly associated with unilateral PA (Table 7).

Table 5 Treatment outcomes of patients with unilateral PA after unilateral adrenalectomy

Clinical success			Biochemical success			ATC/DDD index before surgery	ATC/DDD index after surgery	p value
Absent	Partial	Complete	Absent	Partial	Complete			
2 (4%)	21 (43%)	26 (53%)	0	3 (6%)	46 (94%)	3.3 (2.0-4.3)	0.7 (0.0-1.7)	< 0.01

Data are presented as number (percent), or median (IQR), p value < 0.05 indicates statistically significant. PA: primary aldosteronism; ATC/DDD: total daily dose of antihypertensive agents.

Table 6 Treatment outcomes of patients with PA after spironolactone treatment.

Subtype of patients	Cases	Dose of spironolactone (mg/day)	ATC/DDD index before medical treatment	ATC/DDD index after medical treatment	p value
Unilateral PA	1	50	7.0	3.7	0.31
Bilateral PA	50	25 (25-50)	3.0 (2.0-4.0)	1.7 (1.0-3.3)	< 0.01

Data are presented as number, median (IQR), p value < 0.05 indicates statistically significant. PA: primary aldosteronism; ATC/DDD: total daily dose of antihypertensive agents.

Table 7 Univariate and multivariate analyses for variables associated with unilateral PA

Covariates	Univariate Analysis		Multivariate Analysis	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
PAC ≥ 25 ng/dL	3.8 (1.6-9.2)	< 0.01		
ADRR ≥ 9.36 ng/dL: μIU/mL	12.0 (4.3-33.4)	< 0.01	55.6 (3.2-960.9)	< 0.01
Lowest potassium levels < 2.75 mmol/L	7.3 (2.8-18.6)	< 0.01		
PAC/K ratio ≥ 9.76 ng/dL: mmol/L	5.8 (2.3-14.4)	< 0.01		
Post-RSIT PAC ≥ 15.15 ng/dL	13.1 (4.7-36.2)	< 0.01	24.3 (2.2-272.9)	0.01
Size of adrenal nodule ≥ 1.35 cm	6.4 (1.9-21.2)	< 0.01	20.5 (1.5-276.1)	0.02

p value < 0.05 indicates statistically significant. CI: confidence interval; PA: primary aldosteronism; PAC: plasma aldosterone concentration; ADRR: aldosterone-to-direct renin ratio; RSIT: recumbent saline infusion test; PAC/K: plasma aldosterone concentration-to-potassium.

Discussion

Primary aldosteronism, commonly seen in clinical practice, is linked to increased metabolic, cardiovascular, and renal risk. Somatic mutations in PA are diverse and vary by racial group, affecting clinical presentation.[14] Asians tend to have higher salt sensitivity compared to Western populations.[15] Understanding the clinical and biochemical characteristics of PA across different ethnicities is important. Our study followed PA patients at Thammasat University Hospital for 12 years, assessing clinical features, screening and confirmation tests, subtype classification, and treatment outcomes.

The sex, age, and body mass index of the patients with PA in this study closely resembled those of patients reported in various studies from different countries.[8, 13, 16-18] The duration of hypertension was also comparable to several studies, especially those conducted on Asian populations.[8, 16, 18] Resistant hypertension is a clinical clue that suggests the need to investigate for PA. In our study, approximately 10% of patients had resistant hypertension, which closely aligns with Douma et al.'s report from Greece,[19] but was lower than in studies on Caucasians and Black individuals in the United States.[20] Hypokalemia, another important hallmark in patients with PA, was frequently observed in our study, particularly in those with unilateral PA, who had a higher prevalence of adrenal nodules compared to the bilateral PA group. This finding differs from previous reports from Europe, the United States, and Australia, ranging from 9 to 40%.[2, 21] As a referral center, a higher prevalence of florid PA may have existed. However, the rate of hypokalemia in our study was comparable to that of other studies conducted in Thailand,[8-10] which also reported a significant number of somatic KCNJ5 mutation of aldosterone -producing adenoma,[8] commonly found in Asians and associated with hypokalemia.[22, 23]

The plasma aldosterone concentration levels at the screening test, after discontinuing interfering medications, were moderately elevated which was consistent with findings from several studies in Asian populations.[16,18] The most frequently used confirmatory test in this study was the RSIT, with a positive rate of 66%. Although fewer patients underwent SSIT, it exhibited a 100% positive rate. This may imply that SSIT is more sensitive and superior to RSIT for the confirmation of PA, and this aligns with the study by Stowasser et al.[3]

Adrenal CT scans in this study revealed that the most frequent finding was unilateral nodules, which were more commonly found on the left side, consistent with previous studies.[17] For subtype classification, AVS remains crucial, as it is currently the gold standard.[4] However, a significant limitation of AVS is unsuccessful catheterization. The success rate of bilateral catheterization varies widely among different institutions. Nevertheless, in our center, we achieved a high success rate of 78%, comparable to that of many leading centers both domestically and internationally.[24, 25] Our study observed that the concordance rate for PA subtype classification

between adrenal CT scans and AVS was 68%, corresponding with the 68% reported by Umakoshi et al.[18] and the 77% reported by Mulatero et al.[26] However, our study found that normal or bilateral CT scan results showed up to 83% concordance with AVS, indicating bilateral disease. This finding aided in treatment decision-making with MRAs, especially when combined with other parameters, such as a post-RSIT PAC < 10 ng/dL, as observed by Hashimura et al.[27]

The evaluation of treatment outcomes in the unilateral PA group that underwent unilateral adrenalectomy followed the standardized criteria from The Primary Aldosteronism Surgical Outcome (PASO) study. Our study found that clinical success was evenly distributed between partial and complete, accounting for the majority of those who underwent surgery. However, upon examining biochemical success, it was found that almost all cases achieved complete biochemical success, like previous studies.[12, 28] Moreover, a complete biochemical success confirmed the accuracy of the diagnosis of unilateral PA and indicated that the effects of excess aldosterone on cardiovascular and renal function had been alleviated. However, concerning clinical success, which primarily assesses blood pressure, although almost half of the patients were unable to discontinue antihypertensive medication after surgery, there was a reduction in blood pressure and a decrease in the number of antihypertensive medications. Several factors contribute to high blood pressure, including essential hypertension or long-standing endothelial injury resulting from PA, which may lead to increased peripheral vascular resistance.[29] In the bilateral PA group treated with MRAs, favorable outcomes were observed. Blood pressure control and normalization of serum potassium were achieved with 25 mg of spironolactone per day. This was similar to a study from Singapore.[30] The low doses of spironolactone in bilateral PA may be attributed to several factors. First, bilateral PA in our study exhibited milder severity compared to unilateral PA. Second, the treatment goal may have focused on blood pressure control, influenced by various factors affecting blood pressure in PA patients. Importantly, salt restriction is typically addressed in patient education during routine practice, but its impact on achieving better blood pressure control has not been evaluated. Another significant issue is the failure to titrate spironolactone according to renin levels; ideally, the dosage should be adjusted to achieve unsuppressed renin levels to mitigate potential cardiovascular outcomes.[5]

The variables predicting unilateral PA subtype from univariate and multivariate analyses include ADRR, post-RSIT PAC, and the diameter of the adrenal nodule. ADRR is particularly supported by evidence showing differences between the two subtypes, with a cutoff value like our study.[31] Meanwhile, post-RSIT PAC has been found in several studies to help differentiate subtypes, with post-loading PAC values close to those in our study.[31-33] Additionally, Hashimura et al.'s study[27] found that a post-loading PAC of less than 10 ng/dL assisted in diagnosing bilateral PA. The study by Rossi et al.[34] also found that the size of the culprit nodule was comparable to that in our study.

The strength of this study lies in its comprehensive patient data, which covers screening and confirmation tests, subtype classification, and treatment outcomes within the Thai population, along with its long study duration. Notably, all patients had complete adrenal CT scan data, with a substantial 93% undergoing AVS. However, the study's limitations include its retrospective design, single-center data collection, and potential selection bias from focusing on a tertiary hospital population, which may include patients with florid PA. Additionally, data on post-treatment DRC in the group treated with MRAs are lacking, despite their known association with cardiovascular events.[35]

In conclusion, comprehensive data on PA across different populations help healthcare providers accurately identify PA cases, administer suitable interventions, and tailor treatments. Hypokalemia was frequently observed in Thai individuals with PA. While RSIT remains a reliable confirmatory test, SSIT shows promising performance, but a larger study is needed. Adrenal CT scans remain beneficial for subtyping; however, AVS offers greater accuracy. Treatment with unilateral adrenalectomy or MRAs had excellent outcomes for unilateral and bilateral PA, respectively. Predictors for unilateral PA include high ADRR levels, post-RSIT PAC, and a larger unilateral nodule size.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors have no conflicts of interest

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