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Utility of blood pressure measurements at an initial screening visit to identify Chinese children and adolescents with hypertension

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Abstract

The performance of different BP readings and their combinations at a visit to identify children and adolescents with pediatric hypertension remains controversial. We aimed to assess the utility of different blood pressure (BP) readings and their combinations obtained at the initial screening visit for identifying Chinese children and adolescents with hypertension. Participants were 7831 children and adolescents aged 6-17 years measured as part of a cross-sectional survey conducted in Jinan, China between September 2012 and November 2014. BP was measured three times at up to three visits. Elevated BP at the initial visit was defined as systolic BP and/or diastolic BP ≥ age- and sex-specific 95th percentiles using the Chinese BP references for children and adolescents based on different BP readings and their combinations. Participants with elevated BP using (BP2+BP3)/2 across three visits were defined as having hypertension. Of the different readings or combinations examined, the mean of the last two readings at the initial visit had the best predictive utility for children and adolescents with hypertension (sensitivity: 100.0%; specificity: 86.9%; positive predictive value: 27.6%; negative predictive value: 100.0%). This was also reflected in the area under the curve being highest for the mean of the last two readings (0.93, 95% confidence interval: 0.93-0.94) compared with any of the other readings or combinations (BP1, BP2, BP3, [BP1+BP2]/2, [BP1+BP3]/2, and [BP1+BP2+BP3]/3; all $p < .001$). Taking three measurements of BP and using the average of the last two readings at a screening visit may be optimal for the identification of hypertension in youth.

1 | INTRODUCTION

Pediatric hypertension is a worldwide public health issue.[1] The China Health and Nutrition Survey showed that the prevalence of hypertension in children and adolescents aged 7-17 years in China increased from 8.9% in 1991 to 20.5% in 2015.[2] This is particularly concerning given that elevated blood pressure (BP) persists from childhood to adulthood[3] and children and adolescents with elevated BP have short-term risk of subclinical target organ damages[4,5] and long-term risk of cardiovascular disease and premature death.[6]

Therefore, early screening of BP and identification of those with elevated BP is potentially important in the prevention of adverse consequences later in life.

Given the simplicity, minimal cost, and limited participant burden, most studies that have defined hypertension in pediatric populations use BP readings obtained from only a single visit, but this might increase the number of false-positives.[7,8] However, the performance of different BP readings and their combinations at a visit to identify children and adolescents with pediatric hypertension remains controversial. According to the clinical practice guideline of the American Academy of Pediatrics (AAP), the number of measurements at a visit depends on the level of the initial BP (if BP is elevated at the beginning, then two further measurements should be done).[9] The European Society of Hypertension recommends that BP be measured three times at each visit and the average of the last two readings be used.[10] Besides, a recent cross-sectional study of 5207 children and adolescents 10-14 years of age in Switzerland suggested that obtaining two BP readings and using only the second reading at a visit might be sufficient for the identification of pediatric hypertension.[11] Determining an effective measurement schedule at an initial visit that minimizes clinician time and patient burden might improve the low detection rates of hypertension in children and adolescents.

Therefore, we determined the utility of different BP readings obtained at an initial visit to identify hypertension in children and adolescents using data from a school-based, cross-sectional survey conducted in Jinan, China.

2 | METHODS

2.1 | Study population

Data were from the Twelfth Five-year National Science and Technology Support Program named "Early warning, diagnosis and treatment of childhood cardiovascular diseases" conducted in Jinan, China between September 2012 and November 2014. Four middle-level public schools, including two primary schools, one junior high school, and one senior high school, were selected using a convenient cluster sampling method. All students from the selected schools were invited to complete questionnaires, including demographic information, and undergo physical examinations (ie, height, weight, BP) by trained staff using a standardized protocol. A total of 7831 children and adolescents 6-17 years of age with complete information on age, sex, height, weight, and three BP readings were included. All participants and their parents/guardians signed informed consent forms. The study was approved by the Ethics Committee of the Capital Institute of Pediatrics in Beijing, China.

2.2 | Adiposity measurements and definitions

Weight and height were measured twice using an electronic scale for participants in light clothes without shoes. Weight was accurate to the nearest 0.1 kg, and height to the nearest 0.1 cm. Body mass index (BMI) was calculated as weight divided by the square of height (kg/m^2). Overweight and obesity were defined based on age- and sex-specific BMI cut-offs for Chinese children and adolescents.[12]

2.3 | BP measurements and definitions

After a rest of at least 10 minutes, seated BP was measured three times from the right arm using an electronic sphygmomanometer (OMRON HEM-7012) and an appropriate cuff size with at least 1 minute between repeated measurements.[13] The difference between any two of the three BP readings was less than 5 mmHg.

Elevated BP was defined as systolic BP (SBP) and/or diastolic BP (DBP) ≥age- and sex-specific 95th percentile based on the Chinese BP references for children and adolescents[14] using the first reading (BP1), the second reading (BP2), the third reading (BP3), mean of the first two readings ([BP1+BP2]/2), mean of the first and the third readings ([BP1+BP3]/2), mean of all three readings ([BP1+BP2+BP3]/3), and mean of the last two readings ([BP2+BP3]/2; the reference method) at the initial visit, respectively. Participants with elevated BP using (BP2+BP3)/2 (the reference method) at the first visit underwent a second visit at least 2 weeks later. If elevated BP persisted at the second visit, a third visit was conducted at least another 2 weeks later, according to the same procedures. Participants with elevated BP using (BP2+BP3)/2 (the reference method) at all three visits were defined as having hypertension.

2.4 | Statistical analysis

Continuous variables are presented as mean (standard deviation or standard error), with differences between groups (males vs. females, or BP groups) compared by t test or analysis of variance. Categorical variables are presented as proportions, with differences between groups compared using the chi-square test. Two-by-two crossing tables were used to estimate sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of elevated BP status determined from each reading and their combination (BP1, BP2, BP3, [BP1+BP2]/2, [BP1+BP3]/2, [BP1+BP2+BP3]/3, [BP2+BP3]/2) at the initial visit (yes/no) to identify hypertension determined from three separate visits (yes/no). Receiver operating characteristic curve (ROC) analysis was used to estimate values of the area under the curves (AUCs) with 95% confidence intervals (95% CIs) of elevated BP defined by different readings or combinations to predict hypertension. A two-sided $p < .05$ was considered statistically significant. Data were analyzed using SAS, version 9.4 (SAS Institute, Cary, NC, USA).

3 | RESULTS

Table 1 presents the characteristics of the study participants. The prevalence of systolic hypertension (elevated SBP at all the three

Characteristic	All (N = 7831)	Boys (n = 4076)	Girls (n = 3755)	p value
Age, years	11.3 (3.2)	11.3 (3.2)	11.3 (3.2)	.409
Height, cm	151.1 (17.3)	153.2 (18.5)	148.7 (15.5)	<.001
Weight, kg	47.7 (18.7)	50.9 (20.7)	44.2 (15.4)	<.001
Body mass index, kg/m^2	20.1 (4.6)	20.8 (4.9)	19.3 (4.0)	<.001
Overweight and obesity, %	39.1	47.1	30.4	<.001
Systolic hypertension, %[a]	4.6	6.4	2.7	<.001
Diastolic hypertension, %[a]	1.2	1.2	1.2	.905
Hypertension, %[a]	4.8	6.5	2.9	<.001

TABLE 1 Characteristics of study participants

Note: Continuous variables are presented as mean (standard deviation); Categorical variables are presented as proportions (%).

[a]Reference method based on elevated BP using (BP2+BP3)/2 at all three visits.

visits using the reference method), diastolic hypertension (elevated DBP at all the three visits using the reference method), and hypertension (elevated SBP and/or DBP at all the three visits using the reference method) was 4.6%, 1.2%, and 4.8%, respectively. Boys had higher height, weight, BMI, and a higher proportion of overweight and obesity, systolic hypertension, and hypertension compared with girls (all p < .001).

Table 2 shows the levels of SBP and DBP by reading and their combination at the initial visit. The levels of SBP and DBP decreased, on average, across the three readings. The combinations that included the first reading tended to be higher than the combination that only included the last two readings. Table 3 shows the prevalence of elevated BP, SBP, and DBP by reading and their combination at the initial visit. The prevalence of elevated BP, SBP, and DBP differed by reading and each combination (p < .001). The prevalence of elevated BP, SBP, and DBP was highest based on BP1 (23.4%, 20.4%, 9.3%, respectively), while the prevalence of elevated BP, SBP, and DBP was lowest based on (BP2+BP3)/2 (17.2%, 15.3%, 5.9%, respectively). Similar findings were observed in subgroups stratified by sex (Tables 2 and 3).

BP value, mmHg	All (N = 7831)	Boys (n = 4076)	Girls (n = 3755)
SBP1	111.5 (12.9)	114.2 (13.6)	108.6 (11.4)
SBP2	110.0 (12.9)	112.8 (13.6)	106.9 (11.3)
SBP3	109.3 (12.8)	112.2 (13.5)	106.1 (11.2)
(SBP1+SBP2)/2	110.8 (12.6)	113.5 (13.4)	107.8 (11.0)
(SBP1+SBP3)/2	110.4 (12.6)	113.2 (13.3)	107.4 (11.0)
(SBP1+SBP2+SBP3)/3	110.3 (12.5)	113.0 (13.3)	107.2 (10.9)
(SBP2+SBP3)/2[a]	109.6 (12.6)	112.5 (13.4)	106.5 (11.0)
p value[b]	<.001	<.001	<.001
DBP1	65.8 (8.5)	65.7 (8.6)	65.8 (8.4)
DBP2	64.6 (8.3)	64.6 (8.4)	64.6 (8.2)
DBP3	64.0 (8.3)	64.0 (8.4)	64.0 (8.3)
(DBP1+DBP2)/2	65.2 (8.0)	65.2 (8.1)	65.2 (7.9)
(DBP1+DBP3)/2	64.9 (8.0)	64.9 (8.0)	64.9 (7.9)
(DBP1+DBP2+DBP3)/3	64.8 (7.8)	64.8 (7.9)	64.8 (7.8)
(DBP2+DBP3)/2[a]	64.3 (8.0)	64.3 (8.0)	64.3 (7.9)
p value[b]	<.001	<.001	<.001

TABLE 2 Levels of BP based on different readings and their combinations at the initial visit

Note: Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; SBP1/DBP1, readings of the first measurement at the first visit; SBP2/DBP2, readings of the second measurement at the first visit; SBP3/DBP3, readings of the third measurement at the first visit.

Data are presented as mean (standard deviation).

[a]Reference method.

[b]Difference between BP values calculated using seven methods compared by analysis of variance.

TABLE 3 Prevalence of elevated BP based on different readings and their combinations at the initial visit

	All (N = 7831)	Boys (n = 4076)	Girls (n = 3755)
Elevated BP			
BP1	23.4	26.5	20.1
BP2	19.2	22.5	15.6
BP3	17.8	21.2	14.0
(BP1+BP2)/2	19.7	22.7	16.3
(BP1+BP3)/2	18.7	22.1	15.0
(BP1+BP2+BP3)/3	17.8	20.9	14.5
(BP2+BP3)/2[a]	17.2	20.6	13.5
p value[b]	<.001	<.001	<.001
Elevated SBP			
SBP1	20.4	23.8	16.7
SBP2	16.6	20.5	12.3
SBP3	15.4	19.6	10.9
(SBP1+SBP2)/2	17.6	21.3	13.6
(SBP1+SBP3)/2	16.7	20.5	12.5
(SBP1+SBP2+SBP3)/3	16.1	19.7	12.1
(SBP2+SBP3)/2[a]	15.3	19.1	11.2
p value[b]	<.001	<.001	<.001
Elevated DBP			
DBP1	9.3	9.0	9.6
DBP2	7.6	7.3	7.8
DBP3	6.6	6.1	7.2
(DBP1+DBP2)/2	7.3	6.8	7.9
(DBP1+DBP3)/2	6.7	6.4	7.1
(DBP1+DBP2+DBP3)/3	6.2	5.8	6.7
(DBP2+DBP3)/2[a]	5.9	5.8	6.1
p value[b]	<.001	<.001	<.001

Note: Data are presented as percentages (%).

Abbreviations: BP, blood pressure; BP1/SBP1/DBP1, reading of the first measurement at the first visit; BP2/SBP2/DBP2, reading of the second measurement at the first visit; BP3/SBP3/DBP3, reading of the third measurement at the first visit; DBP, diastolic blood pressure; SBP, systolic blood pressure.

[a]Reference method.

[b]Difference between the prevalence calculated using seven methods compared by the chi-square test.

Table 4 and Figure 1 show the utility of different readings and their combinations at the initial visit to predict hypertension, systolic hypertension, and diastolic hypertension. For hypertension and systolic hypertension, the best predictive utility was obtained with (BP2+BP3)/2 (sensitivity: 100.0%, specificity: 86.9%, PPV: 27.6%, and NPV: 100.0% for hypertension; sensitivity: 96.7%, specificity: 88.7%, PPV: 29.2%, and NPV: 99.8%, for systolic hypertension). The utility of (BP2+BP3)/2 to identify hypertension (AUC [95% *CI*]: 0.93 [0.93-0.94]) and systolic hypertension (AUC [95% *CI*]: 0.93 [0.92-0.94]) was stronger than any of the other readings and combinations (BP1: 0.87 [0.86-0.89], BP2: 0.90 [0.89-0.91], BP3: 0.89 [0.88-0.91],

[BP1+BP2]/2:0.90 [0.89-0.91], [BP1+BP3]/2:0.90 [0.89-0.91], and [BP1+BP2+BP3]/3:0.91 [0.90-0.92] for hypertension; SBP1: 0.87 [0.86-0.89], SBP2: 0.90 [0.88-0.91], SBP3: 0.89 [0.88-0.91], [SBP1+SBP2]/2:0.90 [0.89-0.91], [SBP1+SBP3]/2:0.90 [0.89-0.91], and [SBP1+SBP2+SBP3]/3:0.91 [0.89-0.92] for systolic hypertension; all p < .001). For diastolic hypertension, the sensitivity (57.5%-63.8%), PPV (8.3%-12.0%), and AUC were low (<0.80) for all readings and combinations with no significant difference in AUC observed (all p > .05). Similar findings were observed in subgroups stratified by sex (Table S1; Figures S1-S2).

4 | DISCUSSION

We found that when three individual BP readings are recorded at an initial visit, the mean of the second and third readings performs the best in identifying children and adolescents with hypertension.

As BP has high variability in children and adolescents[15] and generally decreases across consecutive measurements within a single visit,[16] the number of BP measurements at each visit is critical in the identification of pediatric hypertension. One major challenge is how to best balance the increased rate of false positives using limited BP mesurements.[7,8] Among adults, single BP measurement at a visit might not be enough to define hypertension,[17] especially for people with a higher initial BP reading.[18] Similarly, a cross-sectional study from the Australian Health Survey that included 3047 children and adolescents 5-17 years of age underlined the importance of repeated measurements at each visit for the identification of pediatric hypertension.[15] Currently, few studies have examined the number of BP measurements needed at a single visit to identify those with pediatric hypertension. Data from the Kaiser Permanente Southern California Children's Health Study showed that more than half (54.1%) of the children and adolescents 3-17 years of age were misclassified as false-positive cases of hypertension using the initial BP reading at a single visit only, which would lead to unnecessary follow-up.[7] In the present study, we found that the mean value of the last two readings when three BP readings were recorded at a single visit was better than any individual reading to identify those children and adolescents with hypertension. Consistent with our findings, a previous study showed that BP decreases greatly between the first two measurements but less so between the second and third measurements at a visit.[16] These findings suggest that BP should be measured three times at a visit for the identification of hypertension in children and adolescents.

Consistent with our finding, another cross-sectional study among 6694 Chinese children and adolescents 3-17 years of age found that measuring BP three times at a visit and using the average of the last two was optimal for the identification of hypertension among children and adolescents.[16] However, a cross-sectional study including 5207 children and adolescents 10-14 years of age in Switzerland found that the second value of two measurements at a visit might be sufficient for screening elevated BP.[11] Among adults, results have

TABLE 4 Utility of different BP readings and their combinations at the initial visit to predict hypertension based on elevated BP at all three visits

	Sensitivity	Specificity	PPV	NPV	AUC (95% CI)	p for comparison of AUC with the reference method
Hypertension						
BP1	94.6%	80.1%	19.2%	99.7%	0.87 (0.86-0.89)	<.001
BP2	95.2%	84.6%	23.6%	99.7%	0.90 (0.89-0.91)	<.001
BP3	92.5%	86.0%	24.8%	99.6%	0.89 (0.88-0.91)	<.001
(BP1+BP2)/2	96.5%	84.2%	23.3%	99.8%	0.90 (0.89-0.91)	<.001
(BP1+BP3)/2	94.9%	85.2%	24.2%	99.7%	0.90 (0.89-0.91)	<.001
(BP1+BP2+BP3)/3	96.5%	86.1%	25.7%	99.8%	0.91 (0.90-0.92)	<.001
(BP2+BP3)/2[a]	100.0%	86.9%	27.6%	100.0%	0.93 (0.93-0.94)	ref
Systolic hypertension						
SBP1	91.1%	83.0%	20.6%	99.5%	0.87 (0.86-0.89)	<.001
SBP2	92.0%	87.0%	25.5%	99.6%	0.90 (0.88-0.91)	<.001
SBP3	90.0%	88.2%	26.9%	99.5%	0.89 (0.88-0.91)	<.001
(SBP1+SBP2)/2	93.6%	86.1%	24.6%	99.6%	0.90 (0.89-0.91)	<.001
(SBP1+SBP3)/2	92.8%	87.0%	25.7%	99.6%	0.90 (0.89-0.91)	<.001
(SBP1+SBP2+SBP3)/3	93.6%	87.7%	26.9%	99.7%	0.91 (0.89-0.92)	<.001
(SBP2+SBP3)/2[a]	96.7%	88.7%	29.2%	99.8%	0.93 (0.92-0.94)	ref
Diastolic hypertension						
DBP1	63.8%	91.4%	8.3%	99.5%	0.78 (0.73-0.83)	.824
DBP2	59.6%	93.1%	9.5%	99.5%	0.76 (0.71-0.81)	.661
DBP3	57.5%	94.0%	10.4%	99.5%	0.76 (0.71-0.81)	.350
(DBP1+DBP2)/2	61.7%	93.3%	10.1%	99.5%	0.78 (0.73-0.82)	.823
(DBP1+DBP3)/2	59.6%	93.9%	10.6%	99.5%	0.77 (0.72-0.82)	.792
(DBP1+DBP2+DBP3)/3	58.5%	94.4%	11.3%	99.5%	0.76 (0.71-0.81)	.463
(DBP2+DBP3)/2[a]	59.6%	94.7%	12.0%	99.5%	0.77 (0.72-0.82)	ref

Abbreviations: BP, blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; BP1/SBP1/DBP1, readings of the first measurement at the first visit; BP2/SBP2/DBP2, readings of the second measurement at the first visit; BP3/SBP3/DBP3, readings of the third measurement at the first visit; PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve; 95% CI, 95% confidence intervals.
[a]Reference method.

also been inconsistent. A study conducted in Tanzania among 1315 adults 25-64 years of age showed that obtaining three BP readings and using the average of the last two or the third reading at the second visit could be reliable for the assessment of hypertension.[8] Similarly, a study conducted among 678,490 Indian adults aged 31.8 ± 9.2 years showed that BP should be measured three times and the average of the last two readings should be used if the initial BP no less than 140/90 mmHg.[19] However, data from the Atherosclerosis Risk in Communities Study in the US adults suggested that taking two measurements and using the second reading only if the initial BP reading no less than 130/80 mmHg might be an optimal option.[20] Additionally, a cross-sectional study in Nigeria including 410 participants 18-86 years of age found that taking four measurements of BP and using the mean value of the last three measurements at a single visit might be optimal for clinic monitoring.[21] Inconsistency in these results above related to adults might be explained by differences in sample selection, age and race of the participants, sample size, devices used for measurement of BP, and study design.

Regarding the number of visits needed to determine hypertension status in children and adolescents, this is beyond the scope of our study. In the present study, the PPVs (21.3%-32.8%) were low for all individual readings and combinations at the initial visit in predicting hypertension based on three different visits which underlined the need for multiple visits for the confirmation of pediatric hypertension. A previous meta-analysis also suggested that BP measurements on at least three separate visits should be used for the definition of pediatric hypertension.[22] Although the adoption of a single visit strategy is simple, convenient, and economical, which can lead to limited burden for participants, this strategy can also lead to erroneous conclusions because of the large proportion of false-positive cases at one visit. In this study, we would like to answer which BP reading or combination is the best to be used in practice using pediatric hypertension based on three different visits as the outcome, but we did not deny the importance of pediatric hypertension confirmation based on multiple visits.
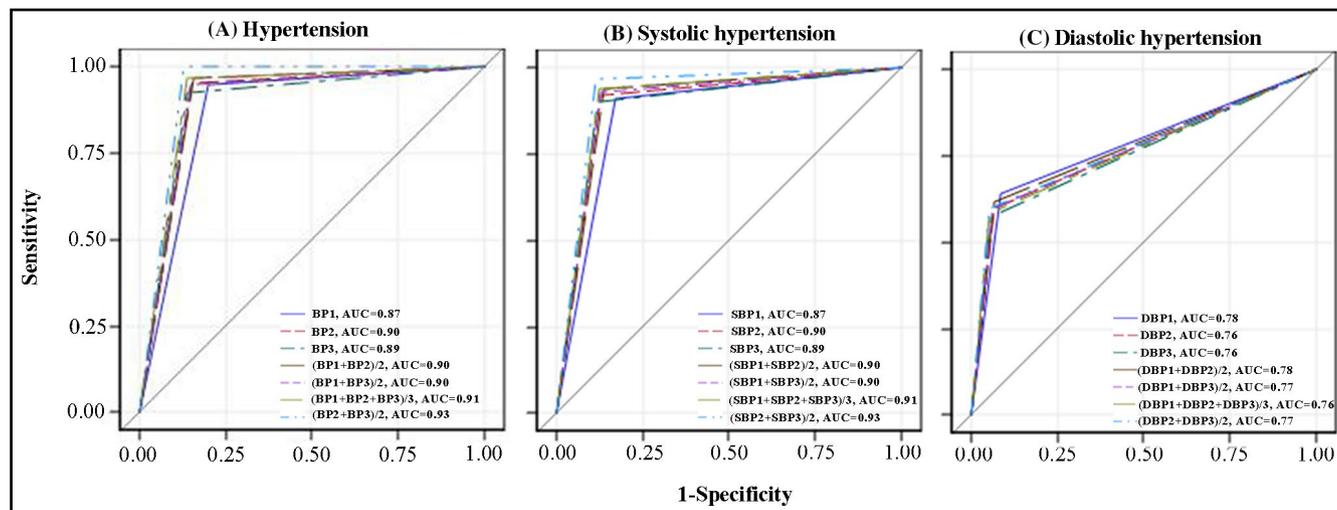
FIGURE 1 ROC curves of different BP readings or their combinations at the initial visit to predict (A) hypertension, (B) systolic hypertension, and (C)diastolic hypertension. Abbreviations: ROC, receiver operating characteristic; AUC, area under the curve; BP, blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; BP1/SBP1/DBP1, readings of the first measurement at the first visit; BP2/SBP2/DBP2, readings of the second measurement at the first visit; BP3/SBP3/DBP3, readings of the third measurement at the first visit

Our study included a large sample size representing a wide age of children and adolescents in China. However, several limitations of our study should be noted. First, subsequent BP visits were only made for those children and adolescents who had elevated BP at the prior visit which may lead to an underestimation of hypertension and misclassification of hypertension status, especially among those with normal BP at the prior visit, but with elevated BP at the subsequent visits. Second, our data were collected using a convenient cluster sampling method of school students in an urban area of Jinan, China, that might not be generalizable to other populations. Third, we used (BP2+BP3)/2 to define hypertension status based on three different visits, which may magnify its predictive utility at the initial visit. Fourth, 24-hour ambulatory BP monitoring and home BP monitoring were not assessed in the present study which may result in misclassification of hypertension.

In conclusion, we found that when three measurements of BP are recorded at a single visit that using the average of the last two readings provides the best utility in identifying children and adolescents with hypertension.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.