

Influence of Physical Activity and Screen Time on the Retinal Microvasculature in Young Children

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Objective—It is not clear whether physical activity and sedentary behavior affect retinal microvascular caliber. We investigated associations among physical activity (outdoor and indoor sporting activities), sedentary behaviors (including screen time, television [TV] viewing, and computer and videogame usage), and retinal microvascular caliber in schoolchildren.

Methods and Results—Six-year-old students (1765/2238) from a random cluster sample of 34 Sydney schools were examined. Parents completed questionnaires about physical and sedentary activities. Retinal images were taken, and retinal vessel caliber was quantified. After adjusting for age, sex, ethnicity, eye color, axial length, body mass index, birth weight, and mean arterial blood pressure, children who spent more time in outdoor sporting activities (in the highest tertile of activity) had $2.2\ \mu\text{m}$ (95% CI 0.65 to 3.71) wider mean retinal arteriolar caliber than those in the lowest tertile ($P_{\text{trend}}=0.004$). Increasing quartiles of time spent watching TV were associated with narrower mean retinal arteriolar caliber $\approx 2.3\ \mu\text{m}$ (95% CI 0.73 to 3.92), $P_{\text{trend}}=0.003$.

Conclusion—These data suggest that physical activity could have a beneficial influence, whereas screen time has a potential adverse influence on retinal microvascular structure. The magnitude of arteriolar narrowing associated with each hour daily of TV viewing is similar to that associated with a 10-mm Hg increase in systolic blood pressure in children. (*Arterioscler Thromb Vasc Biol.* 2011;31:1233-1239.)

Key Words: cardiovascular disease prevention ■ epidemiology ■ exercise ■ microcirculation ■ obesity ■ risk factors ■ Sydney Childhood Eye Study ■ children ■ retinal vascular caliber ■ sedentary behavior

Reduced participation in physical activity coinciding with an increase in sedentary behaviors is thought to contribute to the documented increases in prevalent childhood obesity.¹ The benefits of physical activity in childhood and adolescence are well known.^{2–4} Numerous observational studies have reported inverse associations between physical activity levels and blood pressure (BP) in children and adolescents.^{5–7} Evidence also exists that physical activity and cardiovascular disease (CVD) risk factors track from childhood and adolescence into adulthood.⁸

Conversely, screen time, particularly television (TV) viewing, is associated with higher intakes of energy-dense, nutrient-poor foods and beverages and lower intakes of vegetables.⁹ It is therefore not surprising that TV viewing and screen time are positively associated with childhood adiposity.^{10–12} Several observational studies have also demonstrated that certain indicators of sedentariness, such as screen time, could be potential targets for addressing hypertension in children.^{13–15}

Despite these data, it is not known whether physical activity and sedentary behavior influence the microvascular structure and microcirculation. The retinal blood vessels can be viewed noninvasively, offering a unique opportunity to investigate the effects of obesity, BP, diet, and other CVD risk factors on the microcirculation.¹⁶ Studies in both adult and child populations have shown that changes in retinal microvascular diameter (narrower retinal arteriolar caliber and wider venular caliber) are associated with CVD risk factors, including obesity, components of the metabolic syndrome, and BP.^{16–19} Furthermore, changes in retinal vessel caliber in adults appear to be structural markers of subclinical CVD and predict future vascular events.^{20–22} The influence of physical and sedentary activities on the retinal microvasculature in children has not been investigated.

To develop effective interventions aimed at decreasing future CVD morbidity and mortality, it is important to examine the influence of physical activity and sedentary behaviors on the retinal microvasculature during childhood.

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Hence, we aimed to assess associations among physical activity levels (indoor and outdoor activities), a range of indicators of sedentariness (screen time, TV viewing, computer and video game usage, and reading), and retinal vascular caliber during middle childhood.

Methods

Study Population

The Sydney Childhood Eye Study (incorporating the Sydney Myopia Study) is a population-based survey of eye conditions in school children living within the Sydney Metropolitan Area, Australia. It was approved by the Human Research Ethics Committee of the University of Sydney, the Department of Education and Training, and the Catholic Education Office, New South Wales, Australia.²³ We obtained written informed consent from at least 1 parent of each child, as well as verbal assent from every child before the examinations. Study methods have been previously described for year 1 students from a stratified random cluster sample of 34 primary schools across Sydney (mean age, 6.7 years, hereafter referred to as the 6-year-old cohort).²³ Stratification was based on socioeconomic status data from the Australian Bureau of Statistics. This included a proportional mix of public, private, and religious elementary schools. Study examinations were conducted during 2004 and 2005. Data for the 6-year-old cohort were collected during 2003 and 2004.

Assessment of Physical Activity and Sedentary Behaviors

We collected information on the children's physical activity and sedentary behaviors as reported by the child's parent, because the evidence shows that children younger than 9 to 10 years do not have the cognitive capacity to accurately recall or assess their physical activity and sedentary behavior.^{24–26} The questions relating to physical activity comprised a list of 9 common activities in which early primary-school-aged children participate: (1) dancing, gymnastics, calisthenics; (2) athletics; (3) swimming; (4) football, soccer, rugby league, Australian football; (4) netball, basketball; (5) tennis; (6) Kanga cricket (modified Australian version of cricket for children); (7) skating, riding a scooter, rollerblading; and (8) baseball, softball. Parents were asked to report the number of hours per week their child spent in each of these activities and whether the activity was done out doors or indoors (hall gym, classroom). The time spent in each activity was summed, and the average hours per day spent were calculated separately for outdoor activities, indoor activities, and total activity time (ie, sum of outdoor and indoor activities).

Total screen time (hours per day) was calculated as the time reported that was spent on the following activities: watching TV, using video games, and computer usage (which included using the computer for games and for homework). We also assessed each screen time activity separately and the hours per day spent reading books. Sedentary behaviors comprised screen time and time spent reading.

Retinal Photography and Analysis

Children's eyes were dilated, and digital photographs were taken of the optic disc and macula of both eyes using a Canon 60UVID10 fundus camera (Canon Inc, Tokyo, Japan). Retinal vascular caliber measurements for the right eye of each child were used. Left eye measurements were used if the photographs of the right eye were ungradable. One grader, masked to participant identity and characteristics, measured retinal vessel caliber using a computer-assisted program with high reproducibility, as has been previously described.^{27,28} Average retinal arteriolar and venular calibers were calculated using the Knudtson-Hubbard formula.²⁹

Collection of Other Information

Data were collected during a preorganized visit to each school. Each child's weight and body fat percentage (using leg-leg bioimpedance

Table 1. Characteristics of 6-Year-Old Children Included in the Study

Characteristics	6-Year-Olds (n=1492)
Age, years	6.7 (0.4)
Sex, male, %	50.7
Ethnicity, %	
Caucasian	64.6
East Asian	15.6
Other	19.8
Height, cm	120.7 (5.7)
Weight, kg	23.7 (4.5)
BMI, kg/m ²	16.2 (2.1)
Systolic BP, mm Hg	99.8 (10.6)
Diastolic BP, mm Hg	60.0 (10.6)
Retinal arteriolar caliber, μ m	162.9 (14.0)
Retinal venular caliber, μ m	226.9 (18.3)
Axial length, mm*	22.6 (0.7)
Reported time spent in sedentary behaviors, hours/day	
Reading	0.5 (0.4)
Screen time	1.9 (1.1)
TV viewing	1.2 (0.6)
Computer use	0.4 (0.4)
Video game usage	0.3 (0.5)
Total physical activity, hours/day	0.6 (0.6)
Outdoor sporting activities	0.5 (0.6)
Indoor sporting activities	0.1 (0.2)

Data are mean (SD) or proportions unless otherwise stated.

*Axial length and spherical equivalent of the eye for which data was used throughout the analysis.

analysis) were measured using a Body Composition Analyzer (model TBF-300, Tanita, Tokyo, Japan). Height was measured with shoes off using a freestanding Seca height rod (model 220, Hamburg, Germany). Weight in kilograms was measured using a standard portable weighing machine, after any heavy clothing was removed. Body mass index (BMI) was calculated as weight divided by height squared (kg/m²).

BP was measured on the school premises according to a standard protocol.²³ After 5 minutes resting, BP was measured in a seated position using an automated sphygmomanometer (HEM 907, Omron Healthcare Inc) with appropriate cuff size. We followed general recommendations on selecting cuff size to ensure that the bladder length was $\approx$ 80% and width was $\geq$ 40% of the arm circumference, covering the upper arm without obscuring the antecubital fossa.³⁰ Three separate BP measurements were taken, and averaged for analysis. Mean arterial BP (MABP) was calculated as one third of the systolic plus two thirds of the diastolic BP.

Iris color was assessed from the undilated pupils of each eye and graded by the observer as blue, hazel-green, tan-brown, or dark brown. Axial length was measured before cycloplegia using an optical biometer (IOLMaster, Carl Zeiss Meditec, Oberkochen, Germany) using dual-beam partial coherence interferometry.³¹ The average of 5 measurements was used for analysis.

Parents were asked to complete a comprehensive 193-item questionnaire. Sociodemographic information covering ethnicity, country of birth, education, occupation, and parental age was provided by the parents. Information about the child's birth, such as birth weight, and head circumference was sought. We asked parents to extract this information from their child's health record booklet ("Blue Book"), as reported elsewhere.²³

Table 2. Mean Retinal Arteriolar Diameter and 95% CI Stratified by Time Spent in Physical Activity

Physical Activity (Hours/Day)	N	Retinal Arteriolar Diameter, Mean (95% CI), μm , Multivariable-Adjusted*	Retinal Venular Diameter, Mean (95% CI), μm , Multivariable-Adjusted*
Total physical activity			
Low, <0.29	494	162.7 (160.9 to 164.5)	229.7 (227.7 to 231.6)
Moderate, 0.32–0.68	451	163.1 (161.3 to 164.9)	228.4 (226.4 to 230.5)
High, ≥ 0.71	481	164.4 (162.6 to 166.2)	230.5 (228.6 to 232.5)
<i>P</i> for trend		0.04	0.23
Outdoor sporting activities			
Low, <0.14	511	162.5 (160.9 to 164.1)	229.0 (227.2 to 230.8)
Moderate, 0.18–0.54	426	163.0 (161.0 to 165.1)	228.8 (226.6 to 231.1)
High, ≥ 0.57	487	164.7 (163.0 to 166.5)	229.3 (226.3 to 230.4)
<i>P</i> for trend		0.004	0.19
Indoor sporting activities			
Low, ≤ 0.00	649	163.3 (161.6 to 164.9)	230.5 (228.7 to 232.4)
Moderate, 0.07–0.14	387	164.7 (162.0 to 167.4)	229.0 (226.5 to 231.4)
High, ≥ 0.18	391	162.4 (161.0 to 163.8)	228.2 (226.2 to 230.2)
<i>P</i> for trend		0.22	0.15

*Adjusted for age, sex, ethnicity, iris color, axial length, BMI, birth weight, and MABP.

Statistical Analysis

Statistical analyses were performed using SAS (v9.1, SAS Institute, Cary, NC). Retinal vascular caliber was the dependent variable, and measures of physical and sedentary activities were the independent variables. We assessed each of the physical and sedentary activities as both categorical (quartiles/tertiles, with the lowest quartile/tertile as the reference group) and continuous (per hour per day) variables. Linear regression models were used to estimate the slopes (magnitudes) of a possible linear relationship between physical and sedentary activities and retinal vascular caliber. Adjusted means were compared across levels of physical and sedentary activities. We constructed a multivariable linear regression model that adjusted for age, sex, ethnicity, iris color, axial length of the eyeball, BMI (continuously), birth weight, and MABP.

Results

Of 2238 eligible children aged 6 years (year 1 in school), 1765 children were given parental permission to participate, and 1740 underwent examination (77.7%). Of these, we excluded 106 children without gradable retinal photographs from at least 1 eye, 5 who had various retinal conditions, and 137 who had incomplete physical/sedentary activity data. This left 1492 children (66.7% of those eligible) who were able to be included in this study. On average, 6-year-old children spent an average of 1.9 hours per day of screen time. In contrast, the children spent an average of only 36 minutes per day engaged in total physical activity (Table 1).

Table 2 shows that increasing tertiles of time spent in outdoor sporting activities were associated with wider mean retinal arteriolar diameter after multivariable adjustment ($P_{\text{trend}}=0.004$). Similarly, children in the highest tertiles of time spent in total physical activity had significantly wider mean retinal arteriolar caliber than those in the lower tertiles of activity ($P_{\text{trend}}=0.04$). We found no significant association between physical activity levels and retinal venular caliber (Table 2). Further exploration of the data by additionally adjusting for school term (in Australia, there are 4 school

terms) as an indicator of season in the final multivariate model did not alter our results (data not shown).

Table 3 shows that increasing quartiles of time spent watching the TV was associated with narrower mean retinal arteriolar diameter, after multivariable adjustment ($P_{\text{trend}}=0.003$). Significant narrowing of retinal arteriolar diameter was observed across the increasing quartiles of screen time ($P_{\text{trend}}=0.01$). No significant associations were observed between any of the indicators of sedentary behaviors and retinal venular caliber (Table 3).

Table 4 shows that after multivariable adjustment, each hour per day spent watching TV was associated with, on average, 1.53 μm narrower retinal arteriolar caliber ($P=0.006$). Similarly, each hour per day that 6-year-olds spent in screen time was associated with, on average, a 0.78- μm reduction in retinal arteriolar diameter ($P=0.02$).

Discussion

Retinal arteriolar narrowing is a marker of hypertension in both children and adults, and it has previously been shown to predict CVD in older people.^{32–34} Our findings that schoolchildren engaging in higher levels of physical activity have a better retinal vascular caliber profile (wider retinal arterioles), whereas those spending increased time in screen time have a more adverse retinal microvascular profile (narrower arterioles), suggests that lifestyle factors may influence the microcirculation early in life.

Only a few studies have examined the association between physical activity and retinal microvasculature in adults, but to date, there have been no data from children. The Atherosclerosis Risk in Communities Study³⁵ recently showed that higher levels of physical activity in sport and work domains were associated with a lower prevalence of diabetic retinopathy and arteriovenous nicking and with narrower retinal

Table 3. Mean Retinal Arteriolar Diameter and 95% CI Stratified by Time Spent in Sedentary Behaviors

Sedentary Behavior (Hours/Day)	N	Retinal Arteriolar Diameter, Mean (95% CI), μm , Multivariable-Adjusted*	Retinal Venular Diameter, Mean (95% CI), μm , Multivariable-Adjusted*
Screen time			
1st quartile, <1.07	370	164.1 (162.7 to 165.4)	227.4 (225.8 to 229.1)
2nd quartile, 1.14–1.64	366	162.9 (161.6 to 164.3)	227.8 (226.1 to 229.4)
3rd quartile, 1.71–2.29	376	162.3 (161.0 to 163.6)	227.3 (225.7 to 228.9)
4th quartile, ≥ 2.36	376	161.6 (160.2 to 163.0)	224.9 (223.2 to 226.5)
<i>P</i> for trend		0.01	0.06
Television viewing			
1st quartile, <0.57	457	164.2 (163.0 to 165.4)	227.4 (226.0 to 228.9)
2nd quartile, 0.79–1.14	142	162.9 (160.6 to 165.1)	227.1 (224.5 to 229.7)
3rd quartile, 1.29–1.29	396	161.8 (160.6 to 163.1)	227.7 (226.2 to 229.3)
4th quartile, ≥ 1.50	491	161.9 (160.7 to 163.1)	226.5 (224.1 to 228.9)
<i>P</i> for trend		0.003	0.11

*Adjusted for age, sex, ethnicity, iris color, axial length, BMI, birth weight, and MABP.

venular caliber. The Australian Diabetes, Obesity and Lifestyle Study of 2024 subjects aged 25 years or older showed that men who watched TV for at least 2 hours per day had a venular caliber that was 4.71 μm (95% CI 1.37 to 8.04) wider compared with those watching <2 hours of TV per day.³⁶ Similar associations were not observed in women.

Contrary to the adult population, in schoolchildren we found that arteriolar and not retinal venular caliber was significantly associated with physical activity. The difference between adults and children is most likely due to young children being healthy and largely free of known systemic CVD, unlike the adult population. Moreover, most measures of inflammation increase with age, and certain biomarkers of inflammation are linked with wider retinal venules.³⁷

Six-year-old children who spent the most time engaged in outdoor activity (ie, in 3rd tertile) had wider retinal arterioles compared with those in the lower tertiles of outdoor activity. This suggests that spending approximately an additional half hour per day in outdoor activity could beneficially influence

the retinal vascular profile. The underlying biological mechanisms explaining this association in children are unknown and are likely to be complex. Physical activity enhances arterial endothelial function.³⁸ The mechanism mediating this effect is suggested to be an exercise-induced increase in blood flow, leading to increased shear stress, further causing enhanced nitric oxide production and, thus, improvement in endothelium-dependent vasodilatation.^{39,40} Hence, it is possible that the association of outdoor sporting activities with wider retinal arterioles reflects both structural microvascular changes and pathophysiological processes related to endothelial function. Indeed, recent studies in adults using brachial flow-mediated dilation⁴¹ and light-flicker-induced vasodilation⁴² suggest that retinal vascular caliber changes could be markers of systemic endothelial dysfunction. In the present study, however, we were not able to assess endothelial function; hence, we are not able to confirm whether endothelial dysfunction is a potential mechanism underlying the relationship between time spent in outdoor activity and retinal arteriolar narrowing. Additional studies in children would be needed to answer this question.

In contrast, associations were not observed between changes in retinal vascular caliber and indoor sporting activities. We hypothesize that children participating in indoor sports compared with those playing outdoor sports may cover less total distance, on a lower surface area with lower absolute energy expenditure.⁴³ Consequently, participation in indoor sporting activities may not influence the retinal vascular structure to the same extent as engaging in outdoor sporting activities. However, our findings are not necessarily applicable to other regions (eg, some US cities), where winter is comparatively more severe than the temperate Sydney climate, which could translate to more vigorous levels of indoor sporting activities in these regions. Nevertheless, further adjustment for school term (as an indicator of season) in the analyses did not change our findings. Alternatively, our measures of time spent in physical activity were based on parental report, and the activity questionnaire was not vali-

Table 4. Associations of Sedentary Activities With Mean Retinal Arteriolar Diameter in 6-Year-Old Children

Sedentary Activity (Hours/Day)	Retinal Arteriolar Caliber, Multivariable-Adjusted*		Retinal Venular Caliber, Multivariable-Adjusted*	
	β	<i>P</i>	β	<i>P</i>
Screen time	−0.78	0.02	−0.58	0.08
Television viewing	−1.53	0.006	−0.62	0.28
Video game usage	−0.78	0.34	−1.08	0.18
Computer usage	−0.57	0.50	−1.42	0.09
Reading	1.28	0.16	−0.96	0.29

β -Coefficients refer to each hour/day increase in sedentary activity associated with no. of μm decrease/increase in mean diameter of retinal vascular caliber.

*Adjusted for age, sex, ethnicity, iris color, axial length, BMI, birth weight, and MABP.

dated. Hence, this issue could partially account for the observed inconsistencies between outdoor and indoor activity. Clearly, more research is required to understand the complex relationships between the different types of physical activity and retinal vascular caliber.

Schoolchildren in the lowest quartile of TV viewing time spent an average of <1 hour/day watching TV compared with those in the highest quartile. Hence, reducing TV viewing by as little as an hour a day could be potentially effective in buffering the effects of sedentariness on the retinal microvasculature. TV viewing may also lead to weight gain and sympathetic nervous system activation, both of which may mediate the relationship between TV viewing and elevated BP in children.¹⁵ Given that sedentary behaviors elevate BP levels and that hypertension may contribute to impaired endothelium-dependent vasodilatation,⁴⁴ we cautiously speculate that increased TV viewing via elevated BP may cause narrowing of retinal arterioles. Other mechanisms may include a decrease in resting blood flow as a result of physical inactivity related to TV viewing, which in turn could induce the production of reactive oxygen species and endogenous vasoconstrictors that adversely alter the retinal microvasculature.⁴⁵

In 6-year-old children, on average, a 1.53- μm decrease in retinal arteriolar caliber was observed with each hour per day spent watching TV. This magnitude of change in retinal arteriolar diameter is relatively similar to the arteriolar caliber narrowing of 1.43 to 2.08 μm with each 10-mm Hg increase in systolic BP previously.³² These findings emphasize that the pattern and magnitude of the association of CVD risk factors such as BP and sedentary behaviors with adverse microvascular structural changes are consistent during childhood. However, we stress that differences in arteriolar caliber across the range of time spent in physical or sedentary activity were modest ($\approx 2 \mu\text{m}$). Having said that, we and others have shown that even such small reductions in retinal arteriolar caliber can be associated with moderate changes in BP, eg, each 10-mm Hg increase in systolic BP was associated with a 1.1- μm reduction in arteriolar caliber.^{19,46} The relationship of arteriolar caliber is also graded, and small differences in adulthood can translate into meaningful differences in coronary heart disease risk.²⁰ Furthermore, these studies generally show that relationships were continuous, without any evidence of a threshold, suggesting that any measurable change in retinal vessel diameter is an indicator of an increase in CVD risk. Finally, evidence from autopsy has supported a critical role for microvascular changes in the pathogenesis of CVD and hypertension. For example, Goto et al⁴⁷ directly correlated retinal arteriolar changes with cerebral changes in patients who died from stroke. Given the consistency of the findings between retinal arteriolar narrowing and CVD events, risk factors, and pathology, it is reasonable to infer that any measurable change to the retinal microvasculature in children (ie, subtle arteriolar narrowing) could be a subclinical marker signaling increased risk of CVD, particularly hypertension, in later life.⁴⁸ The long-term follow-up of this and other childhood cohorts will provide additional insights into the clinical significance of our observations (ie, small degree of retinal arteriolar narrowing) during childhood.

In adults, narrower retinal arteriolar caliber predicts an increased future risk of hypertension, diabetes,^{22,49} and incident coronary heart disease.³³ Therefore, our findings are of particular relevance, as modest narrowing of retinal arterioles, possibly linked to increased TV viewing time, is detectable during childhood, well before the onset of other risk factors known to contribute to an individual's CVD risk profile. As narrower retinal arterioles may predict subsequent CVD events in adults,⁵⁰ our study findings could form the evidence base for early preventive action. For instance, relatively cost-effective strategies, such as ensuring that the curriculum for schoolchildren includes a mandatory 2 hours per week of structured physical activity,⁵¹ could potentially translate into future health benefits.

Strengths of this study include its random cluster sample of a large number of representative schoolchildren and the use of standardized protocols to measure retinal vascular caliber. A limitation was the use of parent proxy report rather than an objective measurement of time spent in physical and sedentary activities. The use of such questionnaires in large population surveys is common practice,¹⁴ given the costs (US\$300 per unit), logistics and expertise required to use criterion measures such as accelerometers. Furthermore, parental reports are relatively accurate in estimating time spent by their child in sedentary activities.¹³ Moreover, the consensus from many reviews is that self-reporting should not be used in children younger than 9 to 10 years as they do not have the cognitive capacity to recall or assess their physical activity behavior,^{24–26} and from 9 to 15 years, self-reports should be used cautiously.^{24,52} A second limitation is that the study design is cross-sectional and does not provide temporal information on the associations. However, the most likely direction of the relationship is that time spent in screen time and outdoor activity is related to changes in retinal vessel caliber. A reverse direction of effect (vascular caliber alterations lead to more time spent in screen viewing or less time spent in physical activity) seems unlikely. Third, we cannot exclude the possibility of residual confounding, although we have attempted to adjust for several confounders; it is outside the scope of this analysis to adjust for social and dietary factors. However, these young, healthy children are largely free of known systemic CVDs, and thus, these findings are not likely to be subject to confounding effects. Finally, we did not collect blood samples from our sample of children; therefore, we do not have data on biomarkers of chronic disease, eg, blood lipid levels, blood glucose, and inflammatory markers.

In summary, we have shown for the first time that engaging in higher levels of outdoor activity is associated with modestly wider retinal arterioles in children. However, increased screen time was associated with narrowing of retinal arteriolar caliber. The magnitude of arteriolar narrowing associated with each daily hour of TV viewing is relatively similar to that associated with a 10-mm Hg increase in systolic BP in children. As retinal arteriolar narrowing could be a potential subclinical marker of future CVD risk, the presence of this risk factor may indicate a need for closer monitoring and lifestyle modifications⁵³ to decrease the time schoolchildren spend watching the TV and increasing the time they spend in

physical activity. Our study findings, nevertheless, warrant further longitudinal studies incorporating both objective (eg, accelerometers) and self-report measures of physical activity and screen time in children, to confirm the potential associations between participation in sporting activities and screen time with retinal vascular caliber changes.

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Disclosures

None.

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