Cardiovascular fitness modifies the associations between physical activity and abdominal adiposity in children and adolescents: the European Youth Heart Study

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ABSTRACT

Objective To examine the associations between physical activity (PA) and abdominal adiposity, as measured by waist circumference, in children and adolescents, and to test whether cardiovascular fitness (CVF) modifies these associations.

Methods PA components were measured by accelerometry in 1075 individuals aged 9 or 15 years old. CVF was measured by a maximal cycling test. Self-reported maternal educational level, body mass index, children’s birth weight and television viewing were used as confounders.

Results Linear regression did not show any association between the PA variables and waist circumference, after controlling for sex, age and height. When stratifying by CVF level (low/high), time spent at vigorous PA was inversely associated with waist circumference (p < 0.05) in the low CVF group. Unexpectedly, in the high CVF group, the PA variables were positively associated with waist circumference (p < 0.05). In both groups, the results were unchanged after controlling for the confounders. CVF was inversely associated with waist circumference, after controlling for all PA variables (p < 0.01) and confounders (p > 0.01).

Conclusion CVF is inversely associated with abdominal adiposity and seems to modify the associations between PA and abdominal adiposity. In low-fit children and adolescents, time spent in vigorous PA seems to be the key component linked to abdominal adiposity. This finding should be considered in further development of lifestyle intervention strategies. The results found in the high-fit group need to be confirmed.

Abdominal adiposity, as measured by waist circumference, is associated with a range of risk factors for cardiovascular disease in young people, even within a given body mass index (BMI) category. Factors related to abdominal adiposity should be identified for more efficient health promotion.

Physical activity (PA) is potentially related to abdominal adiposity, but the associations reported so far in this regard are contradictory. Even those studies using objective methods for assessing PA have shown contradictory results in relation to abdominal adiposity.

Cardiovascular fitness (CVF) reflects the overall capacity of the cardiovascular and respiratory systems and the ability to carry out prolonged exercise. The maximal oxygen consumption (VO2max) has long been considered by the World Health Organization as the single best indicator of CVF. CVF seems to be an interacting factor in the relationships between PA and other health outcomes, for example, metabolic risk factors. Whether CVF also interacts in the associations between objectively measured PA and abdominal adiposity remains to be clarified.

CVF has an important genetic component. People genetically predisposed towards having a better fitness level may also be predisposed towards having a lower adiposity status, with PA being less influential. The main hypothesis tested in this study is that those children and adolescents with a low CVF will show a stronger association between PA and abdominal adiposity than their peers with a high CVF level. The purpose of this study was to examine the associations between objectively measured PA and abdominal adiposity in children and adolescents, and to test whether CVF levels modify these associations. Whether the association of CVF with abdominal adiposity is independent of objectively measured PA was also studied.

METHODS

Study population
A total of 557 children aged 9.5 (0.3) years and 518 adolescents aged 15.6 (0.4) years from the Swedish part of the European Youth Heart Study had valid data for waist circumference. Of these subjects, 96% had complete and valid data for sexual maturation status, 88% for maternal educational level, 90% for birth weight, 94% television (TV) viewing, 71% for objectively measured PA and 75% for CVF (ml/min/kgFFM). Study design, sampling procedures, participation rates and study protocol have been reported elsewhere. The study was approved by the Research Ethics Committees of Örebro County Council and Huddinge University Hospital. Written informed consent was obtained from the parents of the children and from both the parents of the adolescents and also from the adolescents themselves.

Physical examination
BMI was calculated as weight/height squared (kg/m²) and used to define overweight (including obesity).
Waist circumference (cm) was measured with a metal anthropometric tape midway between the lower rib margin and the iliac crest, at the end of gentle expiration. The individuals were classified as having a high or low metabolic risk (hereinafter called high-risk/low-risk waist circumference), according to sex and age-specific waist circumference cutoff values.

Skinfold thicknesses were measured with a Harpenden caliper (Baty International, Burgess Hill, UK), according to the criteria described by Lohman et al. Slaughter’s equations were used to calculate the percentage of body fat. Being above the sex-specific and age-specific 85th percentile of body fat percentage was used as a cutoff value for defining individuals with an excess of total adiposity. Fat-free mass (FFM) was derived by subtracting fat mass from total body weight.

Pubertal stage was assessed by a trained researcher of the same sex as the child, using brief observation, according to Tanner and Whitehouse. Breast development in girls and genital development in boys were used for pubertal classification.

Objectively measured PA
PA was measured over four consecutive days (at least two weekdays and at least one weekend day) with an activity monitor (MTI model WAM 7164, Manufacturing Technology, Fort Walton Beach, Florida) worn at the right hip. At least 3 days of recording, with a minimum of 10 h registration per day was set as an inclusion criterion. The epoch duration was set at 1 min.

Total PA was expressed as the total counts recorded, divided by the total daily registered time (counts/min). The time engaged in moderate and vigorous PA was calculated and presented as the average time per day during the complete registration (min/day). Moderate PA (3–6 metabolic equivalents (METs)) and vigorous PA (>6 METs) intensities were based upon cutoff limits published elsewhere. Also, the time spent in at least moderate intensity PA (>3 METs) was calculated (min/day, MVPA).

The accelerometer (CSA/MTI/Actigraph) and the cutoff limits used in this study have shown to be valid for estimating time spent in moderate and vigorous PA in children and adolescents.

Cardiovascular fitness
CVF was determined by a maximal cycle ergometer test. The work rate was preprogrammed on a computerised cycle ergometer (Monark 829E Ergomedic, Vansbro, Sweden), to increase every third minute until exhaustion, as follows: (1) In children (boys and girls) with a body weight of 30 kg or more, the initial work rate was set at 25 W increasing by 25 W every third minute, whereas in those children with a body weight lower than 30 kg, the initial work rate was set at 20 W increasing by 20 W every third minute. (2) In adolescent boys, the initial work rate was set at 50 W, increasing by 50 W every third minute, while in adolescent girls, the initial work rate was set at 40 W, increasing by 40 W every third minute.

Heart rate was registered continuously by telemetry (Polar Sport Tester, Kempele, Finland). The criteria for exhaustion were a heart rate ≥185 beats per minute and a subjective judgment by the test leader that the adolescent could no longer keep up, even after vocal encouragement. The power output (Watts = W) was calculated as = W1*γ(W2*t/180), where W1 is a work rate at the last fully completed stage, W2 is the work rate increment at final incomplete stage, and t is time in seconds at final incomplete stage. The Hansen formula for calculating Vo2max (ml/min) was 12× calculated power output +5× body weight (in kg). For the analysis, CVF normalised by FFM (ml/min/kgFFM) was used.

Confounders
The time spent in TV viewing was self-reported by means of the question “How many hours of TV do you usually watch?” The answer was classed as either <2 h/day or ≥2 h/day. Parents reported their children’s birth weights, and subjects were classed as <2500 g, between 2500 and 4000 g or >4000 g. Maternal height and weight were self-reported, and BMI was calculated. The validity of BMI based on self-reported weight and height in adults has been documented elsewhere. The socioeconomic status was defined by the maternal educational level as below university education and university education.

Statistical analysis
The differences between sex and age groups on continuous variables were assessed by two-way ANOVA (with sex and age as fixed factors). After square root transformation of the vigorous PA and total PA, all the residuals showed a satisfactory pattern. Nominal variables were analysed by χ² tests.

Multiple regression analyses were used to study the associations of PA variables and CVF with waist circumference. Interaction factors (ie, sex×main exposures and age×main exposures) were considered to evaluate whether age and sex modified the associations of PA variables and CVF with waist circumference. Since no interaction was found, all sex and age groups were analysed together. Height influences the observation of fat accumulation and/or distribution, and it should be accounted for when analysing the associations between any factor and waist circumference. Multicollinearity among the exposures was not found in any of the models (variance inflation factor was <10 and averaged variance inflation factor ~1). The PA variables were analysed one by one in all the models to avoid multicollinearity. The statistical analysis performed for this study was split into three steps.

1. The basic model was composed of sex, age group and height. The PA variables or CVF were added to the basic model in separate models to analyse the associations between the exposures and waist circumference, controlling for sex, age and height.

2. The PA variables were consecutively entered into the models together with CVF to examine whether the associations of PA and CVF with waist circumference were independent of each other. Additionally, interaction factors between the main exposure variables (ie, PA variables × CVF) with waist circumference were also analysed.

3. Finally, the associations between PA variables and waist circumference were separately analysed by CVF levels (low/high), and those associations in which interactions found were graphically shown. CVF level was dichotomised (low/high) when being below/above the sex- and age-specific median. All the data were analysed in their continuous form, although data were stratified by quartiles of PA (sex- and age-specific) only for illustrative purposes. In the final model, the analyses were additionally controlled for other potential confounders, such as maternal educational, maternal BMI, birth weight and TV viewing.

All calculations were performed using SPSS V.15.0 software for Windows. For all analyses, the significance level was 5%.
RESULTS

The descriptive characteristics of the participants are shown in table 1. Boys were more physically active and had a higher CVF level than girls. Compared with girls, boys spent 46% more time in vigorous PA and 14% more time in moderate PA.

Standardised regression statistics reporting the associations of either PA variables or CVF with waist circumference, after controlling for sex, age and height, are shown in table 2. No significant association was found between any of the PA variables and waist circumference. CVF was negatively associated with waist circumference after controlling for sex, age and height, are shown in table 2.

DISCUSSION

Young people with low fitness and high fatness levels have an increased risk for metabolic disease33–37 and require special attention. In this study, the prevalence of being overweight, having an excess of total fatness (>85th percentile of body fat) and having a high-risk waist circumference (the Bogalusa study cutoff values) were significantly lower in the high CVF group than in the low CVF group (all p < 0.05; data not shown).

The prevalence of being overweight (IOTF cutoff values), having an excess of total fatness (>85th percentile of body fat) and having a high-risk waist circumference (the Bogalusa study cutoff values) were significantly lower in the high CVF group than in the low CVF group (all p < 0.05; data not shown).
was not affected by other confounders, such as maternal educational level, birth weight or TV viewing. Maternal adiposity is a more important determinant factor predisposing for abdominal fatness than paternal adiposity at childhood and adolescence. After additional controlling for maternal BMI, similar trends were observed. The fact that vigorous PA might benefit the abdominal adiposity status in those children and adolescents at a higher metabolic risk may have implications for the development and testing of lifestyle intervention models.

Follow-up data support that, in obese children and adolescents, exercise is an effective way to promote favourable changes in body composition (ie, decreases in percentage body fat). High levels of vigorous PA, rather than light/moderate PA, have shown to be associated with a lower total adiposity, independently of sex, age, height and abdominal, in young people.

The interactions between CVF and PA in relation to abdominal adiposity found in this study suggest that CVF modifies the associations between PA and abdominal adiposity. This is the first study examining how CVF can influence the associations between objectively measured PA and abdominal adiposity in young people. The high CVF level group showed a lower prevalence of being overweight/obese, having an excess of total fat and having a high-risk waist circumference. Our hypothesis was that in this group of people that already had higher fitness and lower fatness, a weak or even no association between PA and adiposity, both total and abdominal, in young people.

The interactions between CVF and PA in relation to abdominal adiposity found in this study suggest that CVF modifies the associations between PA and abdominal adiposity. This is the first study examining how CVF can influence the associations between objectively measured PA and abdominal adiposity in young people. The high CVF level group showed a lower prevalence of being overweight/obese, having an excess of total fat and having a high-risk waist circumference. Our hypothesis was that in this group of people that already had higher fitness and lower fatness, a weak or even no association between PA variables and abdominal adiposity would be observed. However, the results paradoxically showed that, in these individuals with high CVF levels, all PA variables were positively associated with abdominal adiposity. We checked whether this result could be due to the influence of some potential confounders, such as paternal educational level, maternal BMI, birth weight and TV viewing, but the associations were not affected by any of these factors. Other studies involving objective measurements of PA may confirm or disprove these findings. From an energy balance point of view, this finding would be unexplainable in the case that all the factors that actually influence abdominal adiposity were accounted for (something almost impossible to achieve in practical terms). Unmeasured confounding factors, such as genetic variation and energy intake or dietary patterns, could explain these observations. Only randomisation within a trial can deal with issues of unmeasured confounding.

There is evidence indicating that CVF may interact in the associations between adiposity and metabolic risk. It has been reported that the deleterious consequences ascribed to high fatness could be counteracted by having high levels of CVF. This suggests that the positive associations between PA and waist circumference found in the high CVF level group could have lower relevance for the youths’ cardiovascular health than in the low CVF level group.

The fact that no interaction by sex or age was found suggests that the associations observed in this study are consistent for children and adolescents, and for boys and girls. The sex differences in the association between PA and abdominal adiposity reported elsewhere is not supported by our results. Methodological differences, such as the different accelerometers used in both studies (uniaxial vs triaxial), might explain the discrepancies.

The findings also indicate that CVF is inversely associated with abdominal adiposity, independently of sex, age, height and all the PA variables. We observed similar results in Spanish adolescents from the AVENA study, yet in that case, PA was self-reported. The fact that CVF is associated with abdominal adiposity in children and adolescents, independently of their

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**Table 2** Associations of objectively measured physical activity (PA) variables and cardiovascular fitness (CVF) with waist circumference in children and adolescents

<table>
<thead>
<tr>
<th>Models/exposures</th>
<th>β</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic model (BM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (0 = girls, 1 = boys)</td>
<td>0.018</td>
<td>0.411</td>
</tr>
<tr>
<td>Age (0 = children, 1 = adolescents)</td>
<td>0.014</td>
<td>0.787</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.706</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BM+main exposures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate PA (min)</td>
<td>0.033</td>
<td>0.063</td>
</tr>
<tr>
<td>Vigorous PA (min)*</td>
<td>0.002</td>
<td>0.071</td>
</tr>
<tr>
<td>MVPA (min)</td>
<td>0.044</td>
<td>0.340</td>
</tr>
<tr>
<td>Total PA (counts/min)*</td>
<td>0.009</td>
<td>0.717</td>
</tr>
<tr>
<td>CVF (m/min/FFM)</td>
<td>0.092</td>
<td>0.002</td>
</tr>
</tbody>
</table>

* Standardised linear regression coefficients. MVPA, moderate to vigorous PA. FFM, fat-free mass.

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**Figure 1** Associations of vigorous physical activity (PA) and total PA, with waist circumference in children and adolescents stratified by cardiovascular fitness level (high/low). The quartiles were sex- and age-specifically calculated. Waist circumference was adjusted for sex, age and height.
techniques, including dual energy
similar extent as measurements involving high-technology
variance in a range of cardiovascular disease risk factors to a
people. In addition, waist circumference seems to explain the
MRI.1 Therefore, the use of waist circumference as a surrogate
abdominal fat accumulation49 and visceral adiposity50 in young
methods.

Table 3 Independent associations of objectively measured physical activity (PA) variables and cardiovascular fitness (CVF) with waist circumference in children and adolescents

<table>
<thead>
<tr>
<th>Basic model-CVF+</th>
<th>Main exposures</th>
<th>β</th>
<th>p (β coefficient)</th>
<th>p Value (interaction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate PA CVF</td>
<td>CVF (ml/min/kg FFM)</td>
<td>−0.102</td>
<td>0.005</td>
<td>0.428</td>
</tr>
<tr>
<td>Moderate PA (min)</td>
<td></td>
<td>0.129</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>Vigorous PA CVF</td>
<td>CVF (ml/min/kg FFM)</td>
<td>−0.091</td>
<td>0.014</td>
<td>0.005</td>
</tr>
<tr>
<td>Vigorous PA (min)*</td>
<td></td>
<td>0.011</td>
<td>0.731</td>
<td></td>
</tr>
<tr>
<td>MVPA CVF</td>
<td>CVF (ml/min/kg FFM)</td>
<td>−0.102</td>
<td>0.005</td>
<td>0.257</td>
</tr>
<tr>
<td>MVPA (min)</td>
<td></td>
<td>0.101</td>
<td>0.031</td>
<td></td>
</tr>
<tr>
<td>Total PA CVF</td>
<td>CVF (ml/min/kg FFM)</td>
<td>−0.095</td>
<td>0.011</td>
<td>0.022</td>
</tr>
<tr>
<td>Total PA (counts/min)*</td>
<td></td>
<td>0.027</td>
<td>0.425</td>
<td></td>
</tr>
</tbody>
</table>

MVPA, moderate to vigorous PA.
β Standardised linear regression coefficients. Basic model is composed of sex, age group and height.
Squared root transformed.

Table 4 Associations between objectively measured physical activity (PA) variables and waist circumference in children and adolescents, stratifying by cardiovascular fitness (CVF) level

<table>
<thead>
<tr>
<th>Basic model +</th>
<th>Maternal education</th>
<th>Birth weight</th>
<th>Television viewing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low CVF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate PA (min)</td>
<td>−0.016</td>
<td>0.824</td>
<td>−0.031</td>
</tr>
<tr>
<td>Vigorous PA (min)*</td>
<td>−0.097</td>
<td>0.044</td>
<td>−0.116</td>
</tr>
<tr>
<td>MVPA (min)</td>
<td>−0.046</td>
<td>0.498</td>
<td>−0.063</td>
</tr>
<tr>
<td>Total PA (counts/min)*</td>
<td>−0.084</td>
<td>0.080</td>
<td>−0.113</td>
</tr>
<tr>
<td>High CVF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate PA (min)</td>
<td>0.258</td>
<td>&lt;0.001</td>
<td>0.270</td>
</tr>
<tr>
<td>Vigorous PA (min)*</td>
<td>0.101</td>
<td>0.027</td>
<td>0.101</td>
</tr>
<tr>
<td>MVPA (min)</td>
<td>0.224</td>
<td>0.001</td>
<td>0.231</td>
</tr>
<tr>
<td>Total PA (counts/min)*</td>
<td>0.111</td>
<td>0.015</td>
<td>0.110</td>
</tr>
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MVPA, moderate to vigorous PA.
β Standardised linear regression coefficients. Basic model is composed of sex, age group and height. Maternal education, birth weight and television viewing were one by one sequentially added to the basic model.
Squared root transformed.

objectively measured PA levels, suggests that genetics may play
an important role. Sexual maturation status can modify the
results and interpretations of analyses concerning CVF in young
people,25 so the analyses were also controlled for maturation.
CVF was still significantly associated with abdominal adiposity.
Likewise, confounders such as maternal educational level,
maternal BMI, birth weight or TV viewing did not substantially
affect the associations. The inverse association between physical
fitness and abdominal adiposity in young people has been
consistently reported. It seems to be independent of the
abdominal adiposity measurement method used (high technol-
yogy methods or anthropometry), the physical fitness testing
(running or biking tests) and the physical fitness components
used (CVF, muscular fitness or speed/agility).4 6 7 44–48 This study
contributes to the previous literature by reporting that these
associations seem also to be independent of total PA and
different intensity levels of PA, as measured by objective
methods.

Waist circumference has shown to be an accurate marker of
abdominal fat accumulation26 and visceral adiposity27 in young
people. In addition, waist circumference seems to explain the
variance in a range of cardiovascular disease risk factors to a
similar extent as measurements involving high-technology
techniques, including dual energy x-ray absorptiometry and
MRI.1 Therefore, the use of waist circumference as a surrogate
measurement of abdominal adiposity, and as a powerful index
associated with metabolic risk in young people, seems to be
appropriate for epidemiological studies.

Table 4 Associations between objectively measured physical activity (PA) variables and waist
circumference in children and adolescents, stratifying by cardiovascular fitness (CVF) level

<table>
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MVPA, moderate to vigorous PA.
β Standardised linear regression coefficients. Basic model is composed of sex, age group and height. Maternal education, birth weight and television viewing were one by one sequentially added to the basic model.
Squared root transformed.

Practical implications
The present study shows that vigorous PA is associated with
lower abdominal adiposity in low-fit children and adolescents.
Previous studies have demonstrated that meeting the current PA
recommendations, that is, 60 min/day of MVPA, is associated
with a healthier CVF level but not a lower risk of having high
levels of total and central adiposity.30 51 However, additional
analyses support the hypothesis that 60 min or more of daily PA
could be enough to achieve a healthier fitness and adiposity
status, if enough vigorous PA is accumulated during that period.52
New PA recommendations adapted to young people, and taking
into account the evidence-based importance of vigorous PA, are
needed. In this context, sex-specific and age-specific cutoff values
for vigorous PA associated with a lower risk of being overweight
and having a high-risk waist circumference have been reported by
Ortega et al:38 40 and >25 min/day for children for boys and
girls, respectively, and >20 and >15 min/day for adolescent boys
and girls, respectively.

Also, regular participation in at least 3 h/week of sports
activities and competitions is associated with increased physical
fitness, lower whole body and trunkal fat mass in prepubertal
boys, compared to those individuals not involved in sport/
competition activities.53 These associations are supported by
longitudinal data.54

Finally, data from epidemiological studies using objective
methods for assessing PA and findings from randomised
controlled trials support the idea that high-intensity PA is
associated with higher physical fitness and also that physical
exercise programs, properly designed and controlled, improve physical fitness in children and adolescents, independently of age, maturation and sex. High-intensity PA seems to be a key element for physical fitness enhancement in young people.

These findings, together with those reported from other cohorts, will help to develop future randomised controlled trials and useful intervention strategies based on lifestyle changes in children and adolescents.

Limitations

The present work, as with any other cross-sectional study, only provides suggestive evidence concerning the causal relationship between PA or CVF and abdominal adiposity. The direction of the cause can be suggested but never certainly stated.

The accelerometers do not compensate for the relative increase in energy expenditure by increase in body size and non-weight-bearing activities such as swimming or cycling are not properly measured by the accelerometers. This could also have been a contribution factor to the unexpected results shown in the high-fit individuals.

The method used for assessing CVF has two main limitations:

1. An inherent error must be assumed when VO2max is indirectly estimated. In addition, CVF was expressed as ml/min/kgFFM in this study, and FFM was also indirectly estimated from skinfold thicknesses.

2. Cycling tests give a lower VO2max value than running tests. A possible explanation is that on the cycling tests, the limiting influence of undeveloped knee extensor muscle mass induces local muscle fatigue, with subsequent early end of the test. Also, some youths have difficulty maintaining the proper pedal rate.

Strengths

Despite the limitations highlighted above, accelerometry has proven to correlate reasonably with doubly labelled water-derived energy expenditure and is considered nowadays a method of choice for objectively measuring PA in free-living children and adolescents. The fact that a relatively large sample of children and adolescents were assessed by means of accelerometry in relation to abdominal adiposity, taking into account CVF measured under well-standardised laboratory conditions and a set of relevant confounders, is a notable strength of this study.

CONCLUSION

CVF seems to modify the associations between PA and abdominal adiposity. In low-fit children and adolescents, time spent in vigorous PA seems to be the key PA component linked to abdominal adiposity. This finding may have important implications for further development of lifestyle intervention strategies, since our data suggest that the individuals with a low CVF are actually a high-risk group. Further research examining genetic and dietary factors, in addition to objectively measured PA and CVF, is still needed for a better understanding of the associations between PA and adiposity in young people. Also, the results found in the high-fit group need to be confirmed or disproved in future studies. Finally, our results show that CVF is inversely and consistently associated with abdominal adiposity, independently of the time spent at different intensities of PA and total PA levels.

Acknowledgements

The authors wish to thank Dr Laura Barrios, for her assistance with the statistical analysis of the data, and Dr Luis Moreno, for his valuable comments and scientific support.

Funding

The study was supported by grants from the Stockholm County Council and grants from the Spanish Ministry of Education (EX-2007-1124; EX-2008-0641; DEP2007-29833-E), grants from Swedish Council for Working Life and Social Research, and the ALPHA study (Ref: 2006120).

Competing interests

None.

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