Cardiac Biomarker Release after Endurance Exercise in Male and Female Adults and Adolescents

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Objectives To compare the responses of high-sensitivity cardiac troponin T (hs-cTnT) and NH_2-terminal probrain natriuretic peptide (NT-proBNP) after 60 minutes of swimming in male and female adults and adolescents with different pubertal status.

Study design Adolescent swimmers (25 male and 25 female) and adult swimmers (7 male and 9 female) participated in a 60-minute maximal swimming test with serial assessment of hs-cTnT and NT-proBNP at rest, immediately postexercise, and at 1, 3, 6, 12, and 24 hours postexercise. Adolescents were classified according to pubertal status: Tanner stages 3 (n = 14), 4 (n = 22), and 5 (n = 14).

Results Exercise resulted in an increase in both biomarkers. hs-cTnT responses to exercise were similar in adolescents with different pubertal status and adults, although there was substantial individual variability in peak hs-cTnT, with the upper reference limit exceeding in 62% of the participants. Postexercise kinetics for hs-cTnT were largely consistent across all groups with a return to near baseline levels 24 hours postexercise. The male participants showed higher values of hs-cTnT at baseline and postexercise. All groups had similar NT-proBNP responses to acute exercise and recovery. One swimmer exceeded the upper reference limit for NT-proBNP.

Conclusions An exercise-associated increase in hs-cTnT and NT-proBNP occurred in response to a 60-minute maximal swimming test that was independent of pubertal status/adolescent vs adults. The present data also suggests that baseline and postexercise hs-cTnT values are higher in male compared with female, with no sex differences in NT-proBNP values. *(J Pediatr 2017;■■:■■-■■).*

Cardiac biomarkers are established as part of standard evaluation for the diagnosis and prognosis of patients with myocardial infarction (cardiac troponin T [cTnT] and troponin I [cTnI])[1] and heart failure (NH_2-terminal pro-BNP [NT-proBNP]).[2] Both biomarkers are elevated after prolonged exercise, a physiological stimulus (eg, a marathon[3,4]) as well as shorter bouts of physical activity lasting 30-60 minutes.[5,6] The clinical relevance of these phenomenon is relevant for clinical investigations in athletes after exercise.[7,8]

Most cardiac biomarker data is derived from adults, however, there is a small but consistent dataset suggesting similar responses in adolescents completing prolonged exercise bouts.[9-13] Direct comparison of the release of cardiac biomarkers with exercise in adults and adolescents is limited.[10,14] In a well-controlled study,[10] adolescents demonstrated a peak high-sensitivity cTnT (hs-cTnT) that was 11 times higher than adults after a long-distance run and was still significantly elevated in adolescents at 24 hours of recovery. In contrast, López-Laval et al[14] observed no differences in peak cTnI and postexercise cTnI kinetics during 24 hours of recovery after a basketball match. These contradictory findings may be associated with differences in the pubertal status of adolescents as well as other personal differences (eg, size, fitness, sex) and/or differences in the exercise stimulus. The influence of pubertal status on the postexercise release of biomarkers has only been assessed in a small sample of male adolescent runners.[10] The authors observed a trend toward higher release of hs-cTnT in adolescents of lower Tanner stage, suggesting a role for maturity in mediating hs-cTnT release with prolonged exercise.

There is limited information on the influence of sex on exercise-induced cardiac biomarker release.[11,15,16] Traiperm et al[11] noted similar increases in male and female adolescent marathon runners, but data were limited by assay precision, the number of sampling times postexercise, and the lack of control of the duration/intensity of exercise and pubertal status. In contrast, in a recent study, although limited by

cTnI	Cardiac troponin I
cTnT	Cardiac troponin T
HR	Heart rate
hs-cTnT	High-sensitivity cTnT
NT-proBNP	NH_2-terminal probrain natriuretic peptide
URL	Upper reference limit

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assay precision and by the number of sampling times postexercise, it was observed that after a half-marathon cTnT elevation occurred in all runners but is higher in young male compared with female athletes.[15] No studies in adolescents have evaluated the influence of sex on NT-proBNP values.

We employed multiple sampling points during 24 hours of recovery from a 60-minute swimming time trial to examine the influence of high-intensity aerobic exercise on hs-cTnT and NT-proBNP appearance in male and female adults and adolescents with different pubertal status. Our hypothesis was that the release of hs-cTnT with exercise would be greater in male than in female adolescents , higher in adolescents than in adults, and with the highest values in adolescents with lower maturity status. We hypothesize any influence of sex or adolescent-adult and pubertal status on the release of NT-proBNP with exercise.

Methods

Sixty-six highly trained swimmers were recruited from a large water polo club in Mexico through an open invitation to all of its members. Volunteers included adolescent (25 male and 25 female adolescents, age range = 12-18 years) and adult (7 male and 9 female, adults age range = 22-46 years) swimmers (**Table I**). None of the subjects had any clinical evidence or personal history of cardiac disease or arterial hypertension, and all had a normal 12-lead electrocardiogram at rest. All swimmers provided written informed consent (and parental consent for adolescents). The study followed the ethical guidelines of the Declaration of Helsinki and was approved by the Research Ethics Committee of the Universidad Autónoma de Nuevo León (Autonomous University of Nuevo Leon).

All participants visited the laboratory and swimming pool on 2 occasions. During the first laboratory visit, subjects underwent anthropometric assessment. Body height was measured to the nearest 0.1 cm (SECA 225; SECA, Hamburg, Germany). Body mass was determined to the nearest 0.05 kg (SECA 861; SECA, Hamburg, Germany). The percentage of total body fat was calculated according to Faulkner.[17] A questionnaire was use to obtain training and medical history. Pubertal status was assessed directly by 2 experienced pediatricians according to the standardized Tanner stages based on external primary and secondary sex characteristics.[18] The adolescents were categorized in the middle of puberty, Tanner stage 3 (4 male and 10 female), or late puberty, Tanner stage 4 (11 male and 11 female), and 5 (10 male and 4 female). Finally, maximal heart rate (HR) was recorded using a specific protocol commonly used in training of swimmers consisting of the execution of 6 repetitions of 25 m swimming at maximum intensity with 10 seconds of rest in between repetitions.

In the second visit, the swimmers completed a self-paced 5-minute warm-up (<60% of %HRmax) followed by a 60-minute "all-out" swimming test. All participants were accustomed to the 60-minute all-out swimming test protocol and were asked to abstain from strenuous exercise for 48 hours before the exercise test. During the exercise test, swimmers made a continuous effort without periods of rest time to complete the maximum possible distance at self-paced velocity. The swimming test took place at 08:00 a.m. in a 50-m indoor pool (water temperature 26°C, air temperature 29°C, relative humidity 75%). Pairs of subjects competed side-by-side to provide motivation and competition, and strong verbal encouragement was provided during the test. Subjects were constantly aware of the time and distance covered. Water intake was allowed ad libitum. HR was recorded continuously during the tests via a Polar HR monitor (Polar Team 2; Kempele, Finland). The distance covered was recorded every 10 minutes. The 6-20 ratings of perceived exertion[19] were recorded immediately after the test was completed. Repeated venous blood samples were taken before, immediately after (5 minutes), and at 1, 3, 6, 12,

Table I. Subject characteristics and exercise data

	Adolescents			
	Tanner stage 3 (n = 4 male; 10 female)	Tanner stage 4 (n = 11 male; 11 female)	Tanner stage 5 (n = 10 male; 4 female)	Adults (n = 7 male; 9 female)
Subject characteristics				
Age, y	14.8 ± 1.8†,‡	15.1 ± 1.3†,‡	16.4 ± 1.6‡	31.1 ± 7.9
Height, m	1.59 ± 5.9*,†	1.65 ± 7.6	1.71 ± 7.6‡	1.64 ± 7.0
Weight, kg	51.9 ± 7.6*,†,‡	62.8 ± 12.9†	69.4 ± 12.0	67.5 ± 10.8
Body fat, %	17.5 ± 5.2	18.8 ± 7.3	17.4 ± 6.6	18.4 ± 6.3
Maximum HR, bpm	194 ± 8‡	194 ± 8‡	194 ± 7‡	185 ± 7
Training history, y	2.3 ± 1.6†,‡	2.7 ± 2.0‡	4.8 ± 3.6	7.1 ± 6.4
Training volume, h/wk	18.0 ± 0.0‡	18.0 ± 0.0‡	18.0 ± 0.0‡	14.5 ± 9.5
60-min performance				
Velocity, km/h	3.3 ± 0.4	3.4 ± 0.4	3.5 ± 0.3	3.3 ± 0.4
Mean HR, bpm	163 ± 13	165 ± 16‡	171 ± 11‡	152 ± 16
%HRmax	84 ± 7	85 ± 8	88 ± 6‡	82 ± 9
RPE	18 ± 1	18 ± 1	18 ± 1	18 ± 1

RPE, ratings of perceived exertion.
Values are presented as means ± SD.
*Significantly different from Tanner stage 4.
†Significantly different from Tanner stage 5.
‡Significantly different from adults.

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and 24 hours after exercise to assess serum hs-cTnT and NT-proBNP levels.

Blood samples were drawn from the antecubital vein using venous puncture. The blood was allowed to clot at room temperature and then centrifuged. Serum was drawn off and stored at -80°C for later analysis. hs-cTnT was measured via electrochemiluminescence technology using a Cobas 6000 analyzer (Roche Diagnostics, Tokyo, Japan). This assay has a range from 3 to 10 000 ng/L with a lower detection limit of 3 ng/L. The coefficient of variation at a mean hs-cTnT level of 13.5 ng/L was 5.2%, and the upper reference limit (URL) for hs-cTnT, defined as the 99th percentile of healthy participants, was 14 ng/L.[20] NT-proBNP was analyzed with an Elecsys proBNP electrochemiluminescent immunoassay on a Cobas 6000 analyzer (Roche Diagnostics, Tokyo, Japan) with an analytical range of 5-35 000 ng/L and intra- and inter-assay imprecisions of 0.7-1.6% and 5.3-6.6%, respectively.[21] The URL for NT-proBNP was considered to be 125 ng/L.[22]

Statistical Analyses

Statistical analyses were performed using the IBM Statistical Package for the Social Sciences (IBM SPSS Statistics, v 21.0 for Windows). Cohort data are presented as means ± SD unless otherwise stated. Kolmogorov-Smirnov tests were used to check for normal distribution, and data for hs-cTnT and NT-proBNP were log-transformed before statistical testing. Three-way ANOVA were conducted with 1 within-subject factor (time: pre-exercise and at 5 minutes and 1, 3, 6, 12, and 24 hours postexercise) and 2 between-subject factors (group: Tanner stage 3, 4, 5, and adult; and sex: male and female). To support this analysis, we performed 2-way ANOVAs on peak postexercise hs-cTnT and peak NT-proBNP levels. Finally, we calculated change scores for both biomarkers from pre-exercise to peak postexercise. The association between the exercise increase in both biomarkers and other relevant variables (eg, baseline biomarker concentration, mean HR, and maximal exercise HR) were assessed using the bivariate Pearson product-moment correlation coefficients. Differences were considered significant if $P \leq .05$.

Results

The adolescents were lighter than the adults ($P = .043$) with similar heights and percentage fat values. Adolescents had a higher weekly training volume ($P = .010$) but fewer years of training ($P = .001$). Performance and exercise intensity (%HRmax and ratings of perceived exertion) during the 60-minute all-out test were similar between adolescents and adult swimmers (Table I). Both sexes had similar age and training characteristics, but the female swimmers were shorter and lighter with a higher percentage fat than the male swimmers ($P < .05$). Overall swim performance was lower in the female swimmers, but exercise intensity was similar between sexes (%HRmax: female: 85 ± 8 vs male: 85 ± 8, $P = .919$).

A significant main effect of sampling time was observed for hs-cTnT, which was elevated at 5 minutes, 1, 3, 6, and 12 hours postexercise compared with baseline ($P = .000$; Table II). The hs-cTnT was above the URL in 62% of the participants. The maximum postexercise hs-cTnT values were observed at 1 hour in 2 individuals, 3 hours in 56 individuals, 6 hours in 2 individuals, and 12 hours in 1 individual. There was no evidence of increased hs-cTnT after exercise in 5 subjects: 2 female subjects with Tanner stage 3, 1 female subject with Tanner stage 4, 1 male subject with Tanner stage 5, and 1 female adult. The variability of the hs-cTnT values was lowest at baseline (40%) and highest in the peak postexercise values (145%). There was no main effect of group on the hs-cTnT response to exercise ($P = .578$). The maximal increase in hs-cTnT (peak – baseline) was not significantly different between the groups: Tanner stage 3 (median [range]: 8.9 [0-159.7] ng/L); Tanner stage 4 (median [range]: 16.5 [0-332] ng/L); Tanner stage 5 (median [range]: 19.6 [0-156.7] ng/L); adults: (median [range]: 8.0 [0-117.0] ng/L); $P = .449$. There was a significant main effect of sex with male subjects demonstrating higher values of hs-cTnT

Table II. hs-cTnT (ng/L) before and after 60 minutes of high-intensity swimming exercise

	Adolescents					
	Tanner stage 3 (n = 4 boys and 10 girls)	Tanner stage 4 (n = 11 boys and 11 girls)	Tanner stage 5 (n = 10 boys and 4 girls)	Adults (n = 7 men and 9 women)	ANOVA *P* values	
Pre-exercise	3.0 (3.0-8.6) [0]	3.0 (3.0-7.5) [0]	3.0 (3.0-5.3) [0]	3.0 (3.0-10.0) [0]	Time	.000
5 min	3.5 (3.0-9.6) [0]	4.3 (3.0-36.7) [14]	8.7 (3.0-32.5) [29]	3.0 (3.0-15.0) [13]	Group	.578
1 h	8.1 (3.0-40.4) [36]	13.1 (3.0-145.5) [41]	14.2 (3.0-70.0) [50]	6.0 (3.0-31.0) [31]	Sex	.000
3 h	11.9 (3.0-168.3) [43]	21.0 (3.0-335.0) [77]	22.7 (3.0-135.6) [71]	12.5 (3.0-102.0) [50]	Time × group	.307
6 h	7.9 (3.0-95.9) [36]	13.9 (3.0-170.9) [50]	16.3 (3.0-162.0) [64]	7.1 (3.0-120.0) [31]	Time × sex	.000
12 h	4.3 (3.0-40.0) [21]	6.2 (3.0-62.5) [18]	7.0 (3.0-143.9) [29]	3.5 (3.0-36.0) [13]	Group × sex	.209
24 h	3.0 (3.0-18.5) [7]	3.0 (3.0-26.7) [5]	4.3 (3.0-86.4) [14]	3.0 (3.0-14.0) [6]	Time × group × sex	.135

Data are presented as medians (ranges). Values in brackets are the percentages of subjects with hs-cTnT exceeding the URL.

Table III. NT-proBNP (ng/L) before and after 60 minutes of high-intensity swimming exercise

	Adolescents					
	Tanner stage 3 (n = 4 boys and 10 girls)	Tanner stage 4 (n = 11 boys and 11 girls)	Tanner stage 5 (n = 10 boys and 4 girls)	Adults (n = 7 men and 9 women)	ANOVA *P* values	
Pre-exercise	18.4 (5.0-52.7) [0]	19.4 (5.0-94.4) [0]	12.4 (5.0-37.0) [0]	15.6 (5.0-43.0) [0]	Time	.000
5 min	25.8 (5.3-82.4) [0]	32.8 (5.0-133.5) [5]	24.7 (5.0-53.8) [0]	25.1 (5.0-50.3) [0]	Group	.733
1 h	26.2 (5.6-73.3) [0]	28.1 (5.0-121.2) [0]	24.5 (5.0-56.0) [0]	25.9 (5.8-53.6) [0]	Sex	.119
3 h	26.8 (6.5-70.3) [0]	26.4 (5.0-113.9) [0]	23.8 (5.0-49.8) [0]	28.0 (5.6-60.3) [0]	Time × group	.709
6 h	26.3 (6.3-68.1) [0]	24.7 (5.0-95.7) [0]	24.8 (5.0-46.9) [0]	28.4 (9.0-57.3) [0]	Time × sex	.445
12 h	28.7 (5.3-76.4) [0]	25.3 (5.0-108.0) [0]	30.0 (9.4-53.4) [0]	26.9 (9.8-64.9) [0]	Group × sex	.439
24 h	34.4 (6.3-66.6) [0]	30.4 (5.0-144.3) [5]	20.3 (17.0-63.8) [0]	18.3 (7.5-82.5) [0]	Time × group × sex	.982

Data are presented as medians (ranges). Values in brackets are the percentages of subjects with NT-proBNP exceeding the URL.

(*P* = .000). In addition, a significant interaction was evident between sampling time and sex (*P* = .000). This sex difference in the kinetics of hs-cTnT is a consequence of the female subjects having a delayed peak postexercise (male: 5 minutes post-effort; female: 1 hour posteffort) and a return to baseline (male: 24 hours posteffort; female: 12 hours posteffort). There was no significant interaction between sampling time and group (*P* = .307), sex and group (*P* = .209), or time and group and sex (*P* = .135). The increase in hs-cTnT was significantly associated with the %HRmax (*r* = .339, *P* = .005). The 5 subjects without an increase in hs-cTnT after exercise worked at a lower %HRmax (77 ± 3 vs 85 ± 8, *P* = .019).

There was a significant main effect of sampling time for NT-proBNP, increasing from pre-exercise to 5 minutes and 1, 3, 6, 12, and 24 hours postexercise (*P* = .000; Table III). Only 1 participant exceeded the URL of NT-proBNP. Variable kinetics of NT-proBNP were evident among subjects during recovery, with the peak postexercise values observed at 0 hour (17 individuals), 1 hour (4 individuals), 3 hours (2 individuals), 6 hours (4 individuals), 12 hours (14 individuals), and 24 hours (24 individuals). One subject had no increase in NT-proBNP after exercise. There was no significant main effect of group on the NT-proBNP levels (*P* = .733). In support of the latter point, there was no difference between groups with respect to the maximum increase of NT-proBNP: Tanner stage 3 (median [range]: 15.4 [3.6-38.9] ng/L); Tanner stage 4 (median [range]: 18.7 [0-52] ng/L); Tanner stage 5 (median [range]: 12.6 [4.8-54.9] ng/L); adults: (median [range]: 19.5 [2.8-49.2] ng/L); *P* = .449. There was no main effect of sex on NT-proBNP (*P* = .119). There were no significant interactions between time and group (*P* = .709), time and sex (*P* = .445), sex and group (*P* = .439) as well as time and group and sex (*P* = .982). The peak postexercise level of NT-proBNP was strongly associated with pre-exercise concentration in male (*r* = .742, *P* = .000) and female (*r* = .868, *P* = .000) subjects. There was no correlation between the increases in NT-proBNP and hs-cTnT (*r* = .136, *P* = .277).

Discussion

This controlled study compared postexercise kinetics of cardiac biomarkers in adolescents of both sexes classified according to their pubertal status. Furthermore, this study compared the response of cardiac biomarkers to exercise between adolescents and adults. We found that a single 60-minute bout of all-out swimming resulted in significant increases in hs-cTnT and NT-proBNP in both adolescent and adult swimmers. There was substantial individual variability was noted in peak hs-cTnT during recovery, with the URL exceeded in 62% of the swimmers, although the kinetics of hs-cTnT increase and recovery during the 24 hours postexercise period was more consistent. There was less individual variability in peak NT-proBNP, with 1 subject above the URL, but the kinetics during recovery were inconsistent. The baseline and postexercise levels of both biomarkers were independent of pubertal status and were comparable between the adolescent and adult swimmers. Male swimmers had higher baseline and postexercise hs-cTnT values, but there were no sex differences in NT-proBNP values.

hs-cTnT and NT-proBNP Release Postexercise

This study confirms that the exercise-induced release of cTn and NT-proBNP is not exclusive to an ultra-endurance effort in adult athletes.[5,6,23,24] There is some evidence to suggest that cTn release during prolonged exercise is positively associated with exercise intensity.[25,26] Thus, the high intensity shown by our swimmers could explain the release of hs-cTnT. The percentage of participants exceeding the URL (62%) of hs-cTnT was comparable with the only previous study with male adult swimmers who performed the same exercise test (64%).[23] These results confirmed findings of marked individual variability in the release of hs-cTnT with exercise.[6,10] This variability could partly be explained by differences in the %HRmax between the subjects and could be linked to recent findings

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that suggest that the release of hs-cTnT with exercise is higher in subjects with more training or with better "athletic" status[5,6] who are usually capable of maintaining higher %HRmax values for specific durations of effort. This seems the most probable explanation for the absence in some subjects of hs-cTnT increase after exercise. The %HRmax does not explain all of the variability in the hs-cTnT and high %HRmax values were observed in subjects with negligible release of hs-cTnT and this suggests that some other, currently unknown, factor/process may make participants more or less likely to release cTn in response to exercise. There was much more consistency in the overall "pattern" or "kinetics" of hs-cTnT throughout the 24-hour recovery period. Our data reflect a rapid rise in hs-cTnT in the early hours of recovery, with most of the subjects reaching a peak at 3 hours, with close to complete recovery to baseline at 24 hours. These observations were consistent between individuals and largely agreed with the few studies reporting detailed hs-cTnT kinetics over 24 hours.[6,10,23]

Our results extend to swimming previous findings that NT-proBNP was elevated following short-duration (30-60 minutes), high-intensity exercise in rowers and runners, but with few subjects with values higher than the URL.[5,6] The release of NT-proBNP is largely associated with exercise duration and volume, with little influence exerted by exercise intensity.[25,27] A shorter, 60-minute swim could explain why only 1 subject exceeded the URL of NT-proBNP in the present study. Our study confirms that the variability in pre-exercise values is the key factor of the individual variability in the response of NT-proBNP to exercise.[5,6,10] Our results also confirm that the overall kinetics of NT-proBNP appearance exhibit some heterogeneity, with incomplete recovery to baseline at 24 hours postexercise.[5,6,10] The elevation in NT-proBNP at 24 hours could reflect a temporary reduction in kidney function and changes in cardiac function,[10] but this possibility requires further study.

Pubertal and Adult Status Impact on hs-cTnT and NT-proBNP Release

Several studies have suggested that the cTn release after endurance exercise might be greater among adolescent athletes compared with adults, possibly because of the immature cardiac muscle of the adolescent.[10,12,13,28,29] The results of this study do not support this hypothesis and agree with a previous work in which no differences in cTnI release were observed in a male sample after a basketball match between adolescents and adults.[14] Conversely, in the only other controlled study according to the adolescent-adult condition, the assessment revealed that adolescents runners had a higher mean postexercise value of hs-cTnT, with a greater number of subjects exceeding the peak URL and more time to recovery.[10] One possible explanation for these contradictory findings may be associated with differences in the pubertal status of the adolescents between the studies. Adolescents were Tanner stages 3-5 in the current study, 4-5 in basketball players,[14] and 2-3 in runners[10] suggesting than only early Tanner stage may exert an influence upon hs-cTnT. In runners it was observed that adolescents at Tanner stage 2 had higher peak hs-cTnT than those of Tanner stage 3, although the difference was not statistically significant.[10] Ongoing work should determine the causes of the high between-subject variability. Instead, our results agree with the study evaluating the runners[10] and suggest that adolescent-adult and pubertal status do not influence NT-proBNP release with exercise. This is consistent with our observation that no difference between groups in baseline NT-proBNP exist; this strongly explains postexercise NT-proBNP values.

The Impact of Sex on hs-cTnT and NT-proBNP Release

Our results suggest that there are higher postexercise hs-cTnT values in male than female subjects and that this may be partially explained by higher baseline values in male subjects. Our results reflect that the sex difference in hs-cTnT release is not a consequence of differences in exercise intensity. These results partially agree with those recently observed in male and female adolescent runners.[15] The authors reported that the response of cTnT after endurance exercise was substantially higher in male than female subjects, but at pre-exercise cTnT data were not different between 2 groups. In this study, exercise intensity was not controlled, and, therefore, we cannot rule out this factor as a contaminator variable. The authors also acknowledged the impact of assay choice upon their data. Using the hs-cTnT assay, higher baseline values in male than in female subjects have been previously reported in adults[30] and adolescents.[31] Others researchers have speculated a role for sex hormones to explain the sex differences in resting hs-cTnT concentration[15,31] where as we have speculated a role for sex differences in heart size.[5,6,32,33] This is an area that requires further research and insight to fully explain the mechanism(s) at play behind sex-based differences in the hs-cTnT response to exercise. Our results also confirmed that sex has limited influence on the release of NT-proBNP with exercise.[16] Again, these results may be due to that there are no sex differences in baseline NT-proBNP.

Physiological and Clinical Implications

The clinical implications of exercise-associated changes in biomarkers requires further study. Importantly, elevated hs-cTnT has been demonstrated in most subjects after short-term exercise, which is known to have beneficial effects.[34] The relatively low levels of hs-cTnT and the short time to peak with resolution within 24 hours demonstrated in this and other studies[6,10,23] are somewhat different from those observed for hs-cTnT in cases of acute myocardial infarction.[1] The hs-cTnT increase occurred in the absence of clinical signs and symptoms. Furthermore, the greater values of hs-cTnT seem to be associated with subjects who, likely because of better training/genetic condition, are capable of maintaining an effort at a higher %HRmax. Altogether, these observations suggest that the postexercise hs-cTnT level may reflect a physiological, rather than pathologic, response to the exercise stimulus that may indicate transient cytosolic leakage propagated by membrane damage. From a clinical perspective, there seems to be no strong rationale for full clinical cardiovascular examination in subjects with elevated postexercise hs-cTnT in

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the absence of other clinical signs and symptoms. For medical decision-making, clinicians should know that the release of hs-cTnT with exercise is evident in the majority of subjects and is equally present in adolescents and adults after an intense effort of 60 minutes, with higher values expected in male than in female subjects. Clinicians should also know that after short-duration exercise, NT-proBNP release is expected, likely in response to volume overload and myocyte stretch,[10] at a magnitude typically lower than the URL.

The strengths of the present study include the controlled exercise regimen, matched male and female adult and adolescent swimmers, control of pubertal status, serial blood sampling, assay precision, and measurement of both hs-cTnT and NT-proBNP levels. Several limitations should be considered as follows. (1) Although the release of cardiac biomarkers was higher than previously established regarding biological and analytical variability, the inclusion of a nonexercise control group would have allowed a better insight into this issue (2) Training volume of adolescents was higher than adults, even though the differences were small and both groups were highly trained (3) Differences in the %HRmax achieved in the exercise test among adolescent groups, whereas not significant, may have had a minor influence on the results. (4) The results cannot be extrapolated to the effects of much more demanding exercise tests, (5) or lower Tanner stage male and female subjects. (6) We note the inherent limitation of cross-sectional studies. Future studies should address testing subjects sequentially through adolescence and (7) control of the menstrual cycle may also be of interest in future studies.

In conclusion, 60 minutes of high-intensity swimming results in equivalent elevations and kinetics across a 24-hour recovery period of both hs-cTnT and NT-proBNP in adolescents at Tanner stages 3, 4, and 5 of puberty and in adults. Our results suggest that higher postexercise hs-cTnT values are present in male compared with female subjects because of differences in their respective baseline values. Despite the high variability in post-exercise peak values, the kinetics of hs-cTnT appearance suggests that the exercise-induced release is a physiological process with no known clinical consequences. ■

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