HuSeasonal difference in bone characteristics and body composition of elite speed skaters.

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Abstract

We investigated the changes in bone characteristics and body composition of elite speed skaters across two competitive seasons. Twelve elite speed skaters age (23 ± 4 years; height 1.73 ± 0.09 m; body mass 68.5 ± 8.8 kg; mean ± 1SD) were assessed by DXA and pQCT for Bone Mineral Density (BMD), Bone Mineral Content (BMC), area, bone strength, cortical thickness and density at four points over the course of two competitive seasons. Body composition data was also collected. A main effect of time was shown for whole body BMC, right leg BMC, and trabecular area ($P<0.05$). Whole body BMC was higher during pre-season and end of season in comparison mid-season (1.0%, $P=0.007$; 0.8%, $P=0.017$), right leg BMC was higher at the pre-season scan in comparison to the post pre-season scan (1.8%,$P=0.02$) and trabecular area was higher during the mid-season and end of season when compared to the pre-season (1.4%, $P=0.012$; 1.0%, $P=0.003$). Seasonal changes in bone characteristics and body composition are shown in elite speed skaters over a competitive season. The changes are thought to be as a result of fluctuations in training load. These data may have implications for training design and injury risk management in elite sport.

Introduction

The importance of mechanical loading to ensure optimal bone health is widely acknowledged [25]. The sports that are associated with the greatest osteogenic benefits have been shown to be activities that necessitate irregular movement patterns [9] and a high magnitude of loading [7,18]. This is substantiated by running speed being shown to be related to volumetric bone mineral density (BMD) and cortical area in groups of masters track athletes [28].

Despite studies reporting the osteogenic benefits of certain sports, the time point during the season when the bone measurements were recorded is not commonly reported. This is important due to the changes shown in bone characteristics in athletes over the course of a competitive season (soccer players, [16] rugby league players, [8,10] alpine skiing, [15]). Information related to the time point of the season when bone characteristics are heightened may provide information that is useful for determining the osteogenic impact of differing exercise training. On the other hand, a decrease in bone characteristics, such as bone mineral content (BMC) has been associated with an increased risk of fracture [3], and therefore identification of seasonal time points when bone characteristics are lowered may highlight periods when there is a greater risk of bone injury.

Bone fracture is the second most common type of injury in short track speed skaters, with the ankle being the most common anatomical location of fracture [21]. Short track speed skating is a sport in which training and competition racing involves irregular movement patterns that generate a high magnitude of loading [22]. The specific bone characteristics of short track speed skaters are yet to be fully elucidated, although speed skaters have been shown to have a greater BMD at the distal femur [12] and at the greater trochanter [17] in comparison to a sedentary control population, which is thought to be due to the mechanical loading long track speed skating necessities. However, the previous studies don’t allude to the time point in the season that the assessment of BMD took place and are conducted in either long track speed skaters [17] or don’t stipulate if the participants involved in long track or short track disciplines [12].

Short track speed skating involves traveling at speeds in excess of 50km·h^{-1}, while circling a 111m track for either 500, 1,000 or 1,500m [22]. Due to the skating action and speed at which skaters travel and corner, it is expected that a high magnitude of load is encountered. As skaters navigate the course in a clockwise direction, asymmetrical differences in neuromuscular [6] and muscle oxygenation occur [13] between the right and left leg. Because of this, bilateral differences are expected in bone characteristics and body composition.

Currently, it is not known if the bone characteristics of elite speed skaters differ over the course of the season. Therefore the aim of the present study was to assess if the bone characteristics of elite speed skaters differ over the course of a competitive season and assess if the findings are reproducible following a second season.

Method

Participants

Elite male (n = 6) and female (n = 6) speed skaters (23 ± 4 years; height 1.73 ± 0.09 m; body mass 68.5 ± 8.8 kg; mean ± 1SD) were recruited via previously established links with Nottingham Trent University. Participants were inducted into the study if they were over 18 years of age, on the elite level program, injury free and not taking any form of medication known to influence bone metabolism. Prior to the scans commencing, participants completed a statement of informed consent, pre-scan screening and health screen questionnaire. The study conformed to Ionising Radiation Regulations and was approved by the National Health Service Research Ethics Committee (Reference 15/EM/0037). The study was also conducted in accordance with international standards [11].

Of the 12 speed skaters that volunteered to participate in the study, two were withdrawn due to retriment and illness (Figure 1). The following season male (n = 6) and female (n = 6) speed skaters (age 22 ± 3 years; height 1.69 ± 0.10 cm; body mass 63.6 ± 9.9 kg; mean ± 1SD) were recruited by the same method as previously mentioned. Of the skaters that completed season one, nine took part in season two. The typical training conducted by the elite speed skaters of the course of the season is shown in table 1.

Procedures

Elite world and national level speed skaters were tested for baseline variables during the first week of pre-season training, which included height, body composition and bone characteristics using Dual-energy x-ray Absorptiometry (DXA) (iDXA, GE Healthcare, United Kingdom) and peripheral quantitative computed tomography (pQCT) (XCT2000L, Stratec Medizintechnik, Pforzheim, Germany) over the course of a competitive season. Data was collected using the same methodology during a second season to confirm or refute the findings. Speed skaters completed their regular training and competition season as normal with a repeat of the baseline measures taking place post pre-season, mid-season and at the end of the season. The time span between each scan was as follows: Season 1: Pre-season to Post-season (101.0 days ± 0.0, Post pre-season to Mid-season 76.2 days ± 1.4, Mid-season to End of season 82.2 days ± 5.1. Season 2: Pre-season to Post-season (104.4 days ± 1.8, Post pre-season to Mid-season 97.0 days ± 0.0, Mid-season to End of season 92.4 days ± 2.3). All training was conducted and supervised by qualified coaches at the English Institute of Sport.

Height (Stadiometer, Seca, Hamburg, Germany) and body mass (Seca, Birmingham, U.K.) were recorded with participants wearing minimal clothing. DXA scans assessed participant BMD, BMC, bone area and body composition. Calibration of the DXA was completed prior to scanning, using a manufacturer supplied phantom of a known density. Participants were asked to wear mimimal clothing and remove any jewellery or metal prior to the scan to ensure the validity of the measurements. Participants were asked to be fasted for two hours, void their bladder immediately before and consume 500mL of water at least 1 h prior to the scan to ensure euhydration. Participants were placed in a supine position on the DXA bed within the scanner range, with ankles and knees held in place by Velcro straps to ensure any unintended movements were avoided. Participants were asked to remain as still for the duration of the scan. Scans lasted approximately 10 minutes depending on the size of the participant.

Coefficient of variation for the scan used in the present study has been shown to be 0.075% for BMD and 0.6% for fat mass [19].

The following measures were analysed: whole body lean mass (kg) and % body fat; whole body BMD (g), whole body BMC (g), right leg BMD (g), left leg BMD (g), right leg BMC (g), left leg BMC (g), total bone area (cm^2), right leg area (cm^2), left leg area (cm^2) and Z-score.

pQCT scans were taken of the dominant leg (defined as the leg that the participant most comfortably kicked a ball with), by the same operator. Before scanning commenced, the scanner was cross-calibrated using phantoms of known density in accordance with manufacturer guidelines. Data was analysed you're the integral manufacturer supplied software. pQCT has previously been shown to provide a reliable measurement of bone characteristics in humans by our wider research group [14] and others [1]. The participants' tibial length was measured to the nearest 1 mm, determined as the midpoint of the medial malleolus to the medial aspect of the tibial plateau. The participants leg was then placed in the scanner with their foot secured by a purpose built attachment. The leg was aligned with use of an integral laser and a clamp was placed to the knee to reduce movement, with the participant instructed to remain as still as possible for the duration of the scan. Initially, a preliminary reference point locating scout-view scan was performed in the frontal plane to confirm the location of the middle of the distal end plate, which would act as a positioning line. Sectional images, were then obtained at 4%, 14%, 38% and 66% from the positioning line with a voxel size set at 0.5mm and a slice thickness of 2.5mm for all measurements. A contour mode, with a threshold of $180mg{\cdot}cm^{-3}$, was used to separate soft tissue and bone. To analyse trabecular bone, a constant default threshold of $711mg{\cdot}cm^{-3}$ was used to identify and remove cortical bone. The integral XCT2000L software (version 6.20A) was used to analyse the images.

If any movement artefacts were present following the scan, the image was classed as invalid and a repeat measure was performed. If an artefact was present in the second image the participant was removed from the study in line with radiation exposure guidelines.

The following measures were analysed: 4%: total cross sectional area (CSA, mm^2) and trabecular BMD ($mg \cdot cm^{-3}$).14% and 38%: CSA, (mm^2), cortical CSA (mm^2), cortical BMD ($mg \cdot cm^{-3}$), cortical thickness (mm), periosteal circumference (mm) and stress strain index (SSI,mm^{-3}). 66%: Total CSA, (mm^2) and cortical BMD ($mg \cdot cm^{-3}$).

Statistical analysis

All data are presented as mean ± 1SD. Data were tested for normality using the Shapiro-Wilk test. A repeated measures ANOVA was conducted to assess the effect of time on the bone and body composition characteristics assessed. *Post hoc* test using Bonferroni correction were then conducted to identify the were the differences occurred. The significance level was set at $P <0.05$. Results were interpreted according to the statistical probabilities of rejecting the null hypothesis (H0) and in the following categories: $P > 0.1$: no evidence against H0; $0.05 < P < 0.1$: weak evidence against H0; $0.01 < P < 0.05$: some evidence against H0; $0.001 < P < 0.01$: strong evidence against H0; $< P < 0.001$: very strong evidence against H0. All statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 23.0 (SPSS, Inc., Chicago, IL, USA).

Results

Body composition

A significant effect of time was shown for lean mass ($p = 0.03$) and percentage body fat ($p = 0.009$) over the course of a season (Table 2). Lean mass was significantly lower mid-season when compared to immediately post pre-season ($p = 0.01$, $f = 3.48$, $df = 3$). Percentage body fat was significantly higher before pre-season ($p = 0.007$, $f = 4.73$, $df = 3$) and at the end of the season ($p = 0.05$, $f = 1.01$, $df = 3$) in comparison to post pre-season. No significant changes were shown in body mass (Table 1).

When analysis was conducted following the second season, a significant effect was time was also shown for lean mass ($p = <0.001$) and percentage body fat ($p = 0.019$). Lean mass was significantly lower at the end of season in comparison to post pre-season (52.5 ± 10.7 kg compared to 50.7 ± 10.5 kg; $p = 0.005$; $f = 11.23$, $df = 3$) and during the season (52.5 ± 10.7 kg compared to 51.4 ± 10.4 kg; $p = 0.025$, f = 2.82, df = 3). Percentage body fat was significantly higher at pre-season in comparison to post pre-season (17.5 ± 0.5% compared to 16.3 ± 0.6%; p = 0.02; f = 2.12; df = 3) and mid-season (17.5 ± 0.5% compared to 16.2 ± 0.5%; p = 0.03, f = 1.52, df = 3).

Bone Characteristics

A main effect of time was shown for whole body BMC (p = 0.01), right leg BMC (p = 0.02), right leg BMD (p = 0.006), sub cortical area (p = 0.05), total CSA; 66% site (p = 0.05) and trabecular area (p = 0.05) following analysis from the first season (Table 3 and 4).

Whole body BMC was higher during pre-season and end of season in comparison mid-season (p = 0.007, f = 7.0, df =3; p = 0.017, f = 3.67, df =3; table 2). Right leg BMC (p = 0.02, f = 3.70, df =3) and BMD (p = 0.006; f = 2.76, df 3) were higher at the pre-season scan in comparison to the post pre-season scan. Sub cortical area was higher mid-season and at the end of the season in comparison to pre-season (p = 0.011; f = 2.91, df = 3; p = 0.010; f = 1.97, df = 3) (Table 3). Total cross sectional area at the 66% site of the tibia was higher at the end of the season compared to pre-season (p = 0.011, f = 1.23, df = 3) and post pre-season (p = 0.005; f = 1.51, df = 3). Trabecular area was higher mid-season and at the end of the season in comparison to pre-season (p = 0.012, f = 2.90, df = 3 and p = 0.03, f = 1.10, df = 3) and post pre-season (p = 0.005, f = 0.94, df = 3 and p = 0.023, f = 2.96, df = 3).

Seasonal differences were again shown in whole body BMC (p = 0.03), right leg BMC (p = 0.003), and trabecular area (p = 0.05) following the second season. No differences were shown in right leg BMD, sub-cortical area and total CSA (66% site) following the second season (p >0.05).

In line with the initial season measurements, whole body BMC was higher at the end of the season in comparison to mid-season (2790.5 ± 492.0 in comparison to 2770.2 ± 480.7; p = 0.001, f = 4.71, df = 3). Right leg BMC was also higher at the pre-season scan in comparison to the post pre-season scan (517.0 ± 104.4 in comparison to 511.4 ± 102.3; p = 0.034, f = 3.31, df = 3) in line with the initial season measurements. Trabecular area measurements were also in agreement with the initial analysis, end of season measurements were higher than pre-season measurements (513.8 ± 64.0 in comparison to 504.6 ± 62.1; $p = 0.043$, $f = 1.03$, $df = 3$)

Adjusted for body mass

When data were adjusted for body mass, a significant effect of time was still present for percentage body fat ($p = 0.028$), lean mass ($p = 0.041$), trabecular area ($p = 0.019$), cross sectional area ($p = 0.044$) and total cross sectional area at the 4% tibal site ($p = 0.019$) in the first season. The differences in body fat ($p = 0.019$), lean mass ($p = <0.001$), trabecular area ($p = 0.001$) and total cross sectional area at the 4% tibal site ($p = 0.007$) were also evident in the second season.

Discussion

To the authors knowledge, this is the first study to assess changes in the bone characteristics and body composition of elite speed skaters over the course of a competitive season. Z-scores above zero were maintained at all scan points, showing all athletes were not at risk of osteopinea or osteoporosis, however variations in bone characteristics were shown. The findings, that have been also shown following in a second season of analysis, show that small, but significant changes in whole body BMC, right leg BMC and trabecular area, as well as, lean mass and percentage body fat occur over the course of a competitive season.

The transient decrease in whole body BMC shown in the present study (higher at pre-season and at the end of the season in comparison to the mid-season measurement) may be related to the mechanotransductive governance of bone remodelling. Increased training load during the pre-season period is likely to have up-regulated bone remodelling, as the bone attempts to adapt to the change in the type and frequency of loading placed upon it. A bone remodelling cycle is thought to take approximately three months from start to finish [26] and the bone resorption element is complete within the first four weeks of this cycle [23]. Therefore, the mid-season scan may represent incomplete adaptation to the pre-season training stimulus, although by the end of the season the bone would have adapted to the initial stimulus and thus a greater amount of mineralisation is likely to have occurred by this time.

The change in bone characteristics shown in speed skaters have similarities to bone changes shown to other sports over the course of a season. Greater whole body BMC in elite rugby league players was shown in pre-season when compared to the mid and end of season [10] , while whole body BMD was greater in pre-season when compared to mid-season [8]. Elite football players also show a decrease in BMC of the lower limbs when comparing pre-season to later in the season [16]. This does, however, contrast with some other previous findings; pelvic BMC of elite football players was reported to increase at the end of a season when compared to pre-season and upper limb BMC was shown to increase in direct contrast to the decrease shown at the lower limbs [16]. These findings suggest anatomical site specific changes that might be directly related to the type and magnitude of the loading encountered and the type of bone being loaded. No changes were reported in competitive triathletes when assessing whole body BMC or BMD following 32 weeks of a triathlon season, although detailed training information was not provided and, given that there was no difference in lean mass or percentage body fat between the two assessments, it could be that the triathlon training conducted didn’t fluctuate as much as the sport specific training conducted in the present study and in the previous studies involving team sports [8,10,16]. This fact might explain the differences seen between the studies with respect to changes in bone characteristics across the season.

As well as there being a whole body BMC response to training load, there also seems to be an anatomical site specific response. Right leg BMC was higher in pre-season in comparison to post pre-season, but no differences were shown in the left leg. The different findings in the right leg compared to the left leg in the present study may be due to the asymmetrical nature of loading in short track speed skating. This is the first known study to assess bilateral differences in the bone characteristics of speed skaters, but previous studies have shown differences in the bone characteristics when assessing bilateral sports. The racket arm of tennis players was shown to have greater BMC and cross sectional area in comparison to the non-racket arm [2], while the cortical area and cortical thickness at the 66% site of the tibia were higher in the take-off of leg compared to the non-take-off leg in collegiate long jumpers [27].

Although speed skating is unilateral when skating in a straight line, it has bilateral components when cornering. Cornering generates high ground reaction forces [24], which are likely to be heightened in the right leg when compared to the left leg due to the technique involved when cornering (skater travel clockwise around the rink). The greater amount of loading experienced by the right leg during speed skating performance is characterised by data showing neuromuscular activation [6] and muscle oxygenation [13] to be greater in the right leg in comparison to the left leg. Therefore, the different loading characteristics experienced may explain why changes were only shown in right leg BMC.

The rate of response to mechanical loading is different between trabecular and cortical bone [5], with trabecular bone remodelling more quickly than cortical bone [21]. The increase in trabecular area at the mid-season and end of season assessments when compared to the early season assessments, likely reflects a lag in bone adaptation from the pre-season period. Although speculative, it could be suggested that the increase in trabecular area could be a result of increased bone marrow cavities in preparation for an increase in trabecular density. The reason for the lack of seasonal differences in density related aspects of the tibia may be due to the high basal level of exercise that is taking place, which is not giving adequate time for mineralisation to take place.

Although the different training phases is thought to have caused changes in bone characteristics, whole body BMD Z-scores were above zero at all time points of the season. The current findings showing changes in whole body and right leg BMC over the course of a competitive season may be important for short and long term bone health. Decreased BMC has been associated with increased absolute fracture risk [3] and implicated in the onset of osteoporosis [20]. The reduction in BMC during the post pre-season (right leg) and mid-season (whole body BMC) periods may represent a heightened risk of bone injury in elite speed skaters. Long-term epidemiological studies assessing injury prevalence in speed skaters are, however, required before any cause and effect propositions can be made. The findings showing that intense training in the pre-season period causes a transient drop in BMC may also have implications when designing exercise programs as a method of ensuring positive bone health across the lifespan.

The decrease in lean mass from post pre-season to mid-season and decrease in percentage body fat from pre-season to post pre-season and mid-season are likely to be due to the changes in training load that occurred during the season. The number of gym based sessions decreased during mid-season in comparison to the pre-season period, which may explain the decrease in lean mass, while both gym based sessions and ice sessions increased from the off-season in comparison to pre-season and mid-season period, which explains the differences in body fat. These finding are not unexpected and are in line with changes in lean mass and percentage body fat seen in other sports (Gaelic hurlers [5]; Rugby league players [8,10]; Footballers [16]).

The present study is not without limitation. The cohort used in the present study was relitivley small however, elite athletes are by definition limited in number, and the findings were shown in a second season of analysis, and therefore we are confident that a type I error has not occurred. As the study was applied and conducted in elite athletes, very little control measures were implicated. Due to this, habitual diet and lifestyle preferences were not prescribed by the authors, which could have impacted on the results shown. Unfortunately, altering the daily routines of these elite athletes would have reduced the studies ecological validity and, thus, reduced the applied implications of the study. Specific details in relation to qualification of training load are not know. The lack of precise information makes it difficult to clarify the specific training load that is causing the observed changes in bone characteristics and body composition. As all training was conducted and prescribed by specialist coaches within the national governing bodies' organisation, the authors had no control over measurements taken during training sessions.

In conclusion, BMC (whole body and right leg) and trabecular area change over the course of a competitive season in elite speed skaters. The reason for the changes in bone characteristics is likely to be due to seasonal differences in training load. The decrease in BMC following pre-season training may represent a heightened risk of bone injury during early to mid-season, particularly in the right leg.

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Table 1. The type and duration pf speed skating training conducted over the course of the season.

Type of training	Off-season (Mar-Jun) *Number of occurrences*	Pre-season (Jun-Sept)	Mid-season (Sept-Mar)
Gym (1 h +WU/CD)		3-4	2-3
Aerobic (cycle 1.5-2.5 h/run 30-60 min)	1	1	0-1
Ice (1.5 h on Ice + WU/CD)	5	7-8	7
Imitations (30-60 min)	3-4	2-3	2

WU = warm up; CD= cool down; Ice = training drills and competitions conducted on an ice rink; Imitations = land based rehearsals of the actions typically conducted during speed skating.

Table 2. Body composition measurements from elite speed skaters over the course of a competitive season.

	Pre-season	Post pre season	Mid-season	End-season
Body Mass (kg)	68.5 ± 8.8	67.6 ± 8.9	67.3 ± 9.1	67.7 ± 9.4
Lean Mass (kg)	55.2 ± 9.4	55.7 ± 9.7	55.0 ± 9.1[a]	55.0 ± 9.4[a]
% Body Fat	16.7 ± 0.5	14.8 ± 0.5[b]	15.2 ± 0.5[b]	15.9 ± 0.5

[a] significantly lower in comparison to post-pre-season (p <0.05).

[b] significantly lower in comparison to pre-season (p <0.05).

Table 3. DXA derived bone measurements from elite speed skaters over the course of a competitive season.

	Pre-season	Post pre-season	Mid-season	End-season
WB BMD (g)	1.265 ± 0.120	1.250 ± 0.127	1.261 ± 0.122	1.262 ± 0.130
BMD right leg (g)	1.383 ± 0.145	1.365 ± 0.146[b]	1.369 ± 0.142	1.379 ± 0.158
BMD left leg (g)	1.384 ± 0.129	1.369 ± 0.133	1.376 ± 0.136	1.374 ± 0.139
WB BMC (g)	3044.2 ± 552.9[a]	3020.2 ± 551.2	3012.7 ± 548.1	3035.4 ± 550.1[a]
BMC right leg (g)	575.5 ± 116.3	565.3 ± 114.0[b]	566.7 ± 114.4	571.3 ± 117.8
BMC left leg (g)	579.5 ± 113.0	574.9 ± 113.7	577.2 ± 111.1	578.3 ± 107.6
Total bone area (cm^2)	2393.4 ± 260.7	2397.1 ± 261.6	2375.6 ± 264.6	2392.5 ± 257.0
Area right leg (cm^2)	413.2 ± 47.4	414.3 ± 46.3	410.9 ± 47.4	411.3 ± 47.6

Area left leg (cm^2)	415.9 ± 48.6	417.0 ± 50.1	416.9 ± 48.6	418.9 ± 47.4
Z-score	1.33 ± 1.10	1.24 ± 1.16	1.37 ± 1.11	1.34 ± 1.21

WB = Whole body

[a] Significantly higher in comparison to the mid-season measurement ($P < 0.05$).

[b] Significantly lower in comparison to the pre-season measurement ($P < 0.05$).

Table 4. pQCT derived bone measurements from elite speed skaters over the course of a competitive season.

4%	Pre-season	Post pre-season	Mid-season	End-season
Trabecular Area (mm^2)	566.1 ± 67.8	567.9 ± 68.3	573.8 ± 61.4 ^{a,b}	573.8 ± 68.1 ^{a,b}
Trabecular Density (mg·cm^3)	267.2 ± 20.2	268.3 ± 19.6	268.2 ± 20.0	268.5 ± 20.3
Sub Cortical Area (mm^2)	692.2 ± 82.9	694.4 ± 83.4	701.6 ± 75.1^{a}	701.7 ± 83.2^{a}
Sub Cortical Density (mg·cm^3)	403. 2 ± 45.6	404.3 ± 46.4	399.1 ± 46.7	401.6 ± 46.1
14%				
Cortical Density (mg·cm^3)	1104.3 ± 23.6	1105.6 ± 22.5	1104.9 ± 26.4	1107.5 ± 19.5
Cortical CSA (mm^2)	212.3 ± 46.5	186.1 ± 49.3	201.8 ± 35.5	202.4 ± 35.4
Cortical Thickness (mm)	2.76 ± 0.45	2.64 ± 0.46	2.68 ± 0.49	2.68 ± 0.46
Periosteal Circumference (mm)	85.29 ± 8.96	79.05 ± 15.07	84.01 ± 6.31	84.22 ± 6.69
Strength Strain Index (mg^2/mm^4)	2077.9 ± 633.6	1970.4 ± 480.4	1979.3 ± 431.7	1970.7 ± 403.7
38%				
Cortical Density(mg·cm^3)	1153.9 ± 32.6	1155.2 ± 29.0	1153.9 ± 29.8	1155.9 ± 30.7
Cortical CSA (mm^2)	322.9 ± 56.7	293.2 ± 94.9	326.1 ± 58.3	323.5 ± 55.9
Cortical Thickness (mm)	5.58 ± 0.67	5.19 ± 1.24	5.62 ± 0.72	5.53 ± 0.61
Periosteal Circumference (mm)	75.16 ± 6.31	71.20 ± 12.23	75.43 ± 6.17	75.57 ± 6.08
Strength Strain Index (mg^2/mm^4)	1922.3 ± 467.2	1930.3 ± 497.7	1945.9 ± 477.5	1890.3 ± 398.3
66%				
Cortical Density (mg·cm^3)	1116.0 ± 26.5	1116.2 ± 26.1	1114.8 ± 27.7	1117.6 ± 26.7
Total CSA (mm^2)	772.9 ± 129.4	778.5 ± 136.3	781.1 ± 132.8 ^{a,b}	781.1 ± 127.7^{a,b}

[a] Significantly higher in comparison to the pre-season measurement ($P < 0.05$).

[b] Significantly higher in comparison to the post pre-season measurement ($P < 0.05$).