RELATIONSHIP OF DOCOSAHEXAENOIC ACID (DHA) INTAKE TO CONCUSSION INCIDENCE AND RECOVERY IN THE ADOLESCENT ATHLETE POPULATION

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Sports-related concussion injuries are serious neurological conditions that can result in negative short- and long-term cognitive symptoms, of which adolescent athletes may be at higher risk. Currently, there are no active prevention or treatment strategies for concussion injuries. Docosahexaenoic acid (DHA) supplementation has been proposed as a treatment for concussions due to its important roles in the brain and from rat supplementation studies showing positive effects on mild traumatic brain injury. Additional nutrients may also be important in the incidence and recovery of concussion injuries due to their role in oxidative stress and inflammation. Habitual dietary intake of these nutrients is not well characterized in the adolescent athlete population and no human studies to date have evaluated the effect of dietary intake on concussion incidence and recovery. The aims of this study were to evaluate dietary adequacy of the adolescent athlete population and assess the relationship between nutrient intakes and concussion incidence, recovery, and recurrence. Participants (n=247) included boys' football (n=144) and girls' soccer (n=103) high school athletes. The athletes completed a Youth/Adolescent Food Frequency Questionnaire to evaluate nutrient intake and a baseline ImPACT test to help assess recovery should a concussion injury occur. Concussion diagnoses and recovery course were documented by onsite certified athletic trainers. Nutrient intake was compared to recommended values. Relationships between the dietary variables and concussion incidence and recovery measures were evaluated using logistic regression and Spearman's correlations. Overall dietary quality and DHA intake was poor for boys' football and girls' soccer athletes. Significant individual predictors of concussion diagnosis were percent energy intake from protein, percent energy intake from added sugar, and zinc intake in the overall population and for boys' football athletes. No significant predictors (p>0.05) were identified for the outcome of delayed recovery. DHA intake was not significantly associated (p>0.05) with concussion incidence or measures of recovery. This study highlighted the importance of dietary intervention

and education in the adolescent population, as overall dietary intake was poor. Further research should involve supplementation studies to evaluate the effect of adequate nutrient intake.

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INTRODUCTION

A concussion, also referred to as a mild traumatic brain injury, is a serious neurological injury that results from either a direct or indirect impact to the head (1). The overall annual incidence of sports-related concussion injury in the United States has been estimated to be between 1.6 to 3.8 million (2). Specifically among high school athletes in the United States, the annual incidence rate of concussion from 2008-2010 was reported to be 0.25 per 1000 athletic exposures, which includes every practice and competition in which an athlete participated (3). The high school sports with the greatest concussion incidence have been identified to be boys' football, followed by girls' soccer (3-5). When evaluating gender-specific incidence rates between similar sports, females were more likely to be diagnosed with a concussion injury (3, 4).

The pathophysiology of a concussion injury is complex with a cascade of biochemical changes that affect cellular functioning and metabolism, which can result in various acute clinical signs and symptoms (1, 6, 7). Although pathological changes in brain anatomy are not typically seen on neuroimaging tests directly after a concussion injury, cellular dysfunction can increase the risk of acute and long-term alterations in brain function (1). Acute symptoms usually resolve within 7-10 days after concussion injury; however, some individuals, especially individuals with recurrent concussions, can experience prolonged symptoms and may develop long-term effects (1). Individuals are at increased risk of recurrent concussion injuries if another impact occurs during the recovery phase of a previous concussion injury, due to impaired cellular functioning and metabolism, which can persist even when physical symptoms are resolved (7-9). Adolescent athletes may also be at an increased risk of recurrent concussion injuries due to the continued development of the brain, more athletic exposures with earlier initiation of sport participation, poor understanding of the symptoms and severity of concussion injuries, and pressure to return to play (10). Recurrent sports-related concussions have been linked to multiple negative lingering and long-term effects including cognitive decline, memory impairment that may predict early onset of dementia and Alzheimer's disease, slower motor functioning, depression, and long-term structural changes in the brain (11-17). Growing knowledge of the long-term consequences of concussion injuries highlights the importance of prevention, diagnosis, and full recovery from concussion injuries before returning to play, especially in children and adolescents.

Currently, cognitive and physical rest is the most common approach to treatment, as high levels of physical activity and activities that require more cognitive functioning like reading or problem solving have been shown to exacerbate and prolong concussion symptoms (1, 6, 10, 18, 19). Another more active treatment that has recently emerged is the participation in light physical activity that does not worsen concussion symptoms, which is particularly relevant to the athletic population during a prolonged concussion recovery to minimize the effects of detraining (1, 20, 21). Medications can be useful in treating individual symptoms like headache, sleep disturbances, and mood disorders, but currently, there is no pharmacological treatment for the concussion injury itself (6, 10, 18-21). Considering the high incidence of sports-related concussion injuries and the potential negative long-term effects, discovering active prevention and treatment strategies is important.

One such strategy that has been proposed to reduce the incidence and severity of concussion injuries, due to its multiple structural and functional roles in the brain, is supplementation with docosahexaenoic acid (DHA), an omega-3 long chain polyunsaturated fatty acid (PUFA). DHA found in the human body can either be derived from the omega-3 fatty acid precursors of α-linolenic acid (ALA) and eicosapentaeoic acid (EPA), although this conversion has been shown to be inefficient in humans (22), or through direct dietary consumption. DHA is preferentially incorporated into cell membrane phospholipids of the central nervous system, especially the brain, where its unique structure increases membrane fluidity and flexibility, which may influence the lateral movement of molecules in the membrane, the activity of transmembrane proteins, and the membrane's ability to resist damage from mechanical forces (7, 22-26). In addition, DHA in the membrane can be cleaved from phospholipids and used to activate transcription factors, produce anti-inflammatory eicosanoids, activate cellular signaling cascades via various G-protein coupled receptors, and effect the transmission of neuronal signals through its influence on the activity of ion pumps or channels (7, 22, 23, 26, 27).

Although most of the past research on the relationship between DHA intake and concussion severity/outcomes has been conducted in rat models, the results have supported the possibility of adequate DHA intake as a preventative and/or therapeutic treatment for concussion injuries in humans. DHA supplementation before and after concussion injury has been shown in rats to decrease markers of axonal injury and death, with a dosage of 40 mg/kg/d being the most effective (7, 24, 28). DHA supplementation in rats has also been shown to normalize levels of molecules involved in the transmission of neuronal signals, markers of oxidative stress, molecules that affect membrane structure, and molecules involved in cognitive function, as well as improve functional measures of cognition (7, 29, 30). In addition to adequate DHA intake, a few other dietary components are of interest in the prevention and treatment of concussion injury due to their role in oxidative stress, inflammation, or as an adjunct treatment for severe traumatic brain injury (TBI). These nutrients that may also affect the incidence and severity of concussions include saturated fat, trans fat, total monounsaturated fatty acids (MUFA), oleic acid, total polyunsaturated fatty acids (PUFA), total omega-3 fatty acids, the omega-6/omega-3 fatty acid ratio, added or refined sugar, fiber, zinc, magnesium, vitamin D, vitamin E, vitamin C, flavonoids, and carotenoids (31-36).

To our knowledge, there is no research evaluating the adequacy of dietary intake, specifically of DHA, in the adolescent athlete population in the United States. The adolescent athlete population is at high risk for concussion injuries and associated long-term consequences, for which there is currently a lack of active preventative or treatment strategies. DHA has been proposed as a potential therapeutic agent to reduce the incidence and severity of concussions; however, to our knowledge, there is no research evaluating the relationship between DHA intake and concussion incidence nor outcomes in the adolescent athlete population. The purpose of this study is to assess the dietary adequacy of nutrients related to concussion injury in the adolescent athlete population and to evaluate the relationship between habitual dietary intake, specifically of DHA, and concussion outcomes. We hypothesize that habitual dietary intake of DHA, gathered from Youth/Adolescent Food Frequency Questionnaires (YAQ), will be inadequate in the adolescent athlete population when compared to published recommendations. We also hypothesize that lower DHA intake will significantly predict concussion incidence and delayed recovery.

METHODS

Subject Selection

Participants included boys' football (n=144) and girls' soccer (n=103) athletes 13-18 years of age from three high schools across the Salt Lake Valley that contract with The Orthopedic Specialty Hospital (TOSH) in Murray, Utah for sports medicine services. Signed approval was obtained by the associated school districts. Participants were recruited at each team's coach/athlete/parent meetings during the summer months (May-July) prior to the beginning of both the 2013 and 2014 fall sports seasons, at which time all athletes and their parent(s)/guardian(s) were required to attend by the head coaches. Athletes enrolled in the study on a voluntary basis and consent/assent forms were signed by all athlete participants and, if needed, their parent/guardian. This study was approved by the Intermountain Healthcare Institutional Review Board.

Experimental Design

This study was a longitudinal, prospective, observational study design. Baseline ImPACT testing, provided by the TOSH Sports Medicine team and the TOSH Concussion Clinic, was performed on each new athlete and on returning athletes who had not been tested during the previous fall season. Permission to access prior reports was given by returning athletes who had completed ImPACT testing in the previous year. Participants then completed the Youth/Adolescent Food Frequency Questionnaire (YAQ), which was administered by a Registered Dietitian Nutritionist, to assess dietary intake and supplement use. Throughout the 2013 and 2014 fall football and soccer competition seasons, concussions were diagnosed by onsite certified athletic trainers (ATC) employed by the TOSH Sports Medicine team via standard protocols including SCAT-2 testing (37). Athletes diagnosed with a concussion injury were referred to the TOSH Concussion Clinic for follow-up clinical assessment and repeat ImPACT testing performed via appointment. Return to play decisions were made by the respective ATCs serving each of the three high schools and the TOSH Concussion Clinic via standard procedures including the graduated return to play protocol and repeat ImPACT testing (37). Documentation of concussion incidence, time to complete the return to play protocol, and recurrence for each participating athlete was kept by the ATC at each high school. Information on concussion injuries was gathered from each ATC and the TOSH Concussion Clinic through injury/clinical records. Identifiable information from each participant was blinded from all researchers except the primary and secondary investigator.

Concussion Diagnosis/Recovery

Certified Athletic Trainers employed by TOSH, who serve each of the participating three high schools across the Salt Lake Valley, documented concussion incidence, recovery, and recurrence information including time to return to play for each athlete during the 2013 and 2014 fall sports seasons. Athletic trainers also referred each athlete who was diagnosed with a concussion to the TOSH Concussion Clinic for further clinical evaluation and follow-up. Documentation from each athletic trainer and medical records from the TOSH Concussion Clinic were used to gather data on concussion rates, time to return to play, and recurrence. Total length of time between concussion diagnosis and return to play, and time to complete the graduated return to play protocol were used as measures for concussion recovery, with duration longer than five days to complete the graduated return to play protocol indicating a delayed recovery. Overall and sport-specific estimated concussion rates were calculated and reported as the number of concussions per estimated athletic exposures, which are defined as the number of games and practices the athlete participated in during the 2013 and 2014 fall sports seasons.

Dietary Assessment

The Youth/Adolescent Food Frequency Questionnaire (YAQ) was used to assess the dietary intake of each participating athlete over the previous year. The YAQ has been previously validated to assess dietary intake in this age group, with an estimated completion time of approximately 20 minutes (38). Through collaboration with the head coach of each team, the first

30 minutes of a regularly scheduled practice was reserved for participants to receive instruction and subsequently complete the YAQ. All completed YAQs were sent to Channing Laboratory (Boston, MA) to be processed for individual nutrient intakes (39). Dietary components evaluated in relation to concussion injuries included total energy, carbohydrate, protein, fat, saturated fat, trans fat, DHA, total MUFA, oleic acid, total PUFA, total omega-3 fatty acids, the omega-6/omega-3 fatty acid ratio, added sugar, fiber, zinc, magnesium, vitamin D, vitamin E, vitamin C, flavonoids, and carotenoids. If available, amounts of the aforementioned nutrients were assessed both with and without supplemental intake. Reported dietary intake of each of these nutrients from the YAQ was compared to set recommendations as follows: carbohydrate and protein intake in grams were compared to Recommended Dietary Allowance (RDA) values for 14-18 year old males and females, and percent energy intakes from carbohydrate, protein, and fat were compared to each Accepted Macronutrient Distribution Range (AMDR) (40); carbohydrate and protein intake in g/kg were compared to recommendations for athletes (41, 42); trans fat, percent energy intake from saturated fat, and percent energy intake from added sugar were compared to recommendations from the Dietary Guidelines for Americans (43); DHA intake was compared to the recommendation for healthy adults from the Dietary Guidelines for Americans of 2 servings of seafood each week or about 250 mg/day (44) and also the proposed recommendation for concussion treatment in humans of 387 mg/day (7); the omega-6/omega-3 fatty acid ratio was compared to the published recommendation of 1-2:1 (36); fiber was compared to the Average Intake (AI) amounts for 14 to 18-year-old males and females (40); and zinc, magnesium, vitamin D, vitamin E, and vitamin C intakes were compared to the Estimated Average Requirement (EAR) amounts for 14 to 18-year-old males and females (40).

Statistical Analysis

All statistical analyses were completed using Stata (v14.1, College Station, TX). A 95% confidence level (α=0.05) was used to determine significance. Data were excluded if reported energy intake on the YAQ was <500 or >5000 kcal/day (n=1), which were previously designated as the limits of plausibility (45). All other nutrients were assessed for implausible values and none were identified, leaving 247 participant data records for statistical analysis. Descriptive characteristics of the participants were collected using the YAQ and included sex, age, height, and weight. Body mass index (BMI) was calculated from the reported height and weight. Participants who did not report their weight on the YAQ (n=3) were excluded from the weight and BMI calculations. Concussion incidence rates for the overall group, boys' football athletes, and girls' soccer athletes were each calculated by dividing the number of diagnosed concussion injuries by the estimated number of athletic exposures over the 2013 and 2014 fall sports seasons, and were reported per 1000 athletic exposures. The calculated concussion incidence rates were compared to previously reported high school sports concussion rates (3, 4) using one-sample two-sided t-tests.

Dietary adequacy of boys' football and girls' soccer athletes was assessed for the nutrients described above by comparing the average group intakes to published recommendations, if available, using one-sample two-sided t-tests, and also by calculating the proportion of participants meeting the published recommendations. Simple logistic regression was used to assess the predictive ability of age and BMI, as well as each dietary component, for the outcome of concussion diagnosis in the overall sample and the subpopulations of boys' football and girls' soccer athletes. The predictor variables of sex, age, DHA intake, and other identified significant predictor variables from the simple logistic regression analyses were used to build a multiple logistic regression model to predict concussion diagnosis.

Participants diagnosed with concussion injuries were then evaluated separately. Dietary adequacy of these participants was assessed as described above for the overall group. The relationship between total length of recovery and the variables of age, BMI, and each dietary component were evaluated using Spearman's correlations for the overall sample and the subpopulations of boys' football and girls' soccer athletes. Simple logistic regressions were performed to assess the predictive ability of age, BMI, and each dietary component for the outcome of delayed recovery from concussion injury.

RESULTS

Demographic Characteristics and Concussion Incidence of All Participants

One participant was excluded from analysis due to an implausible reported energy intake, leaving a total of 247 participant data records (144 boys' football athletes and 103 girls' soccer athletes) for analysis. The demographic characteristics and concussion incidence of the study participants are shown in Table 1. The average age of participants was 15.3 years, with a range of 13 – 17 years, and the average age was similar for boys' football and girls' soccer athletes at 15.4 and 15.1 years, respectively. The average overall and sport-specific BMI values were within the normal category (Table 1). The average BMI for boys' football athletes was 24.2 kg/m^2, with a range of 18 – 41 kg/m^2. The average BMI for girls' soccer athletes was 21.2 kg/m^2, with a range of 17 – 34 kg/m^2. The overall concussion incidence rate for the 2013 and 2014 fall sports seasons was 0.70 per 1000 athletic exposures. The concussion rates for boys' football and girls' soccer athletes were 0.78 and 0.59 per 1000 athletic exposures, respectively.

Dietary Adequacy of All Participants

The proportion of boys' football and girls' soccer athletes meeting published recommendations for selected nutrients or dietary components are given in Figure 1, by total intake and intake without supplements, if available. The mean intakes of the assessed nutrients or dietary components for the overall group and for each sport are given along with published recommendations, if available (Table 2). DHA intake among the participants was poor with only 7.6% of boys' football athletes and 4.9% of girls' soccer athletes meeting the general recommendation for healthy adults. When comparing DHA intake to the proposed recommendation for the treatment of concussion injuries in humans, only 2.8% of boys' football athletes and 2.9% of girls' soccer athletes met the recommendation (Figure 1). The average intake of DHA for all participants was 110 mg/d, while the average intake was 118 mg/d for boys'

Table 1. Overall and Sport-Specific Demographic Characteristics and Concussion Incidence

	Overall (n=247)		Boys' Football (n=144)		Girl's Soccer (n=103)	
Variable		P-value[1]		P-value[1]		P-value[1]
Age (yr)	15.3 ± 1.1	0.5	15.4 ± 1.0	0.576	15.1 ± 1.1	0.055
Height (m)	1.71 ± 0.1		1.77 ± 0.07		1.63 ± 0.07	
Weight (kg)	68.4 ± 16.1		76.6 ± 15.1		56.7 ± 8.4	
BMI (kg/m^2)	23.0 ± 3.9	0.705	24.2 ± 4.2	0.672	21.2 ± 2.6	0.282
Concussion Incidence (per 1000 athletic exposures)	0.70		0.78		0.59	

Note: Age, height, weight, and BMI reported as mean ± sd

[1] P-values indicate ability to predict concussion diagnosis from simple logistic regression

[A] denotes significant (p<0.05) predictor of delayed recovery

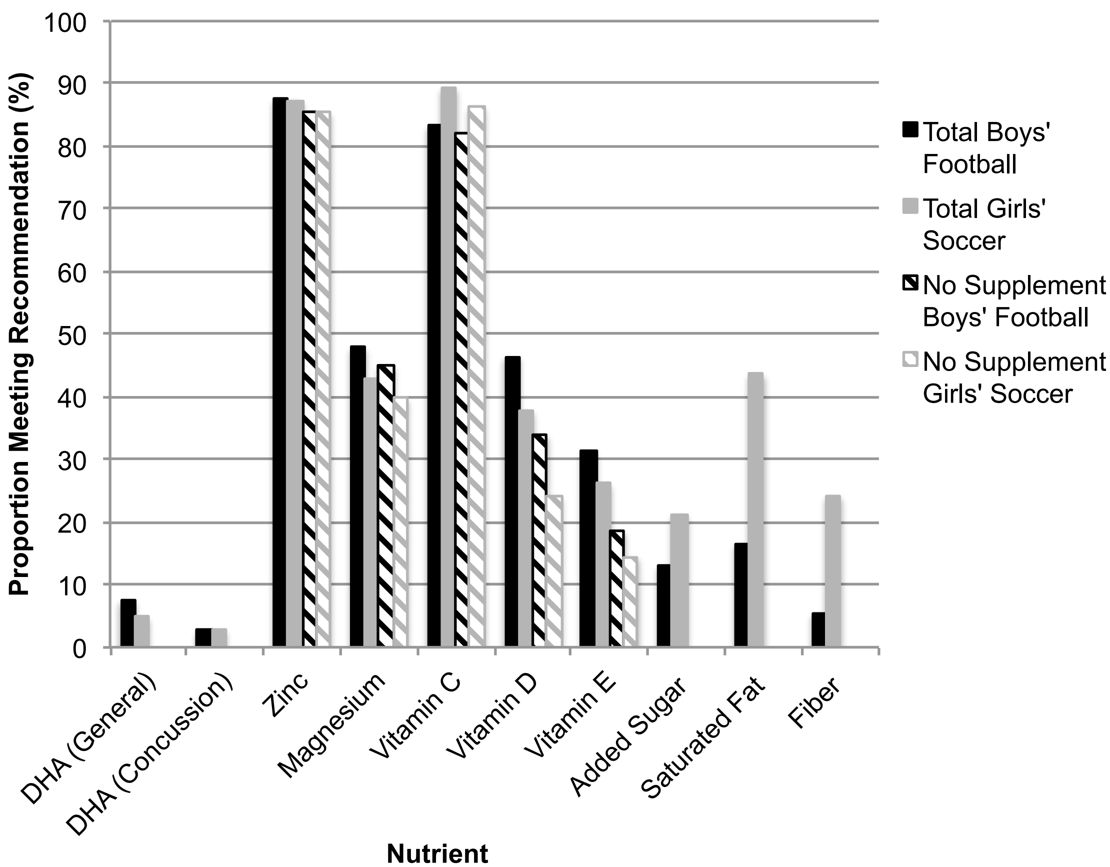

Figure 1. Proportion of Boys' Football and Girls' Soccer Athletes Meeting Recommendations for Nutrient Intake With and Without Supplementation.

Table 2. Overall and Sport-Specific Daily Macronutrient and Micronutrient Intake of Boys' Football and Girls' Soccer Athletes

		Overall		Boys' Football		Girls' Soccer	
	Published Recommendation	Mean ± SD	P-value [1]	Mean ± SD	P-value [1]	Mean ± SD	P-value [1]
Energy		2181 ± 828	0.969	2360 ± 901	0.886	1930 ± 639	0.454
Carbohydrate (g)	130	300 ± 119	0.973	320 ± 131 *	0.885	271 ± 93 *	0.422
(g/kg)	6-10	4.5 ± 1.9	0.523	4.3 ± 1.9 *	0.859	4.8 ± 1.8 *	0.24
(% energy)	45-65	55 ± 5	0.632	54 ± 5	0.377	56 ± 5	0.968
Protein (g)	52 (males); 46 (females)	93 ± 35	0.506	100 ± 37 *	0.565	83 ± 29 *	0.418
(g/kg)	1.2-1.7	1.4 ± 0.6	0.284	1.3 ± 0.5	0.694	1.5 ± 0.6	0.283
(% energy)	10-30	17 ± 3	0.042 [A]	17 ± 3	0.039 [A]	17 ± 3	0.661
Fat (g)	ND	70 ± 29	0.673	78 ± 31	0.667	60 ± 22	0.581
(% energy)	25-35	29 ± 4	0.545	30 ± 4	0.638	28 ± 4	0.982
Saturated Fat (g)		26 ± 11	0.922	29 ± 12	0.772	21 ± 9	0.322
(% energy)	<10%	11 ± 2	0.737	11 ± 2 *	0.77	10 ± 2 *	0.573
Trans Fat (g)	As little as possible	2.6 ± 1.2	0.177	2.9 ± 1.3	0.151	2.2 ± 0.9	0.67
DHA (mg)	250 (general); 387 (concussion)	110 ± 118	0.152	118 ± 125 *	0.191	100 ± 108 *	0.473
MUFA (g)		24 ± 10	0.581	26 ± 10	0.628	20 ± 7	0.689
Oleic Acid (g)		22 ± 9	0.543	25 ± 10	0.6	19 ± 7	0.724
PUFA (g)		14 ± 6	0.601	15 ± 7	0.705	12 ± 5	0.974
Omega-3 Fatty Acids (g)		1.5 ± 0.7	0.827	1.6 ± 0.7	0.696	1.3 ± 0.6	0.95
without supplements		1.4 ± 0.7	0.954	1.5 ± 0.7	0.871	1.3 ± 0.6	0.922
Omega-6:Omega-3 Ratio	1-2:1	8.7:1	0.096	8.9:1 *	0.11	8.5:1 *	0.77
without suppelments		8.9:1	0.307	9.1:1 *	0.250	8.7:1 *	0.858
Added Sugar (g)		76 ± 44	0.384	87 ± 49	0.35	60 ± 29	0.457
(% energy)	<10%	13 ± 5	0.026 [A]	14 ± 5 *	0.027 [A]	12 ± 3 *	0.881
Fiber (g)	38 (Males); 26 (Females)	21 ± 9	0.366	21 ± 9 *	0.438	21 ± 8 *	0.69
Zinc (mg)	8.5 (Males); 7.3 (Females)	15.0 ± 7.0	0.017 [A]	15.6 ± 7.1 *	0.048 [A]	14.1 ± 6.8 *	0.119
without supplements		13.2 ± 5.2	0.095	13.9 ± 5.5 *	0.165	12.2 ± 4.6 *	0.228
Magnesium (mg)	340	341 ± 132	0.211	354 ± 141	0.315	322 ± 116	0.337
without supplements		334 ± 129	0.295	346 ± 137	0.412	317 ± 115 *	0.39
Vitamin D (IU)	400	399 ± 250	0.093	419 ± 248	0.357	370 ± 251	0.076
without supplements		318 ± 174	0.189	345 ± 189 *	0.402	280 ± 144 *	0.126
Vitamin E (mg)	12	12.4 ± 13.6	0.449	13.2 ± 5.5	0.201	11.4 ± 11.4	0.165
without supplements		8.4 ± 4.0	0.209	8.5 ± 4.0 *	0.363	8.2 ± 4.1 *	0.341
Vitamin C (mg)	63 (Males); 56 (Females)	162 ± 114	0.068	164 ± 117 *	0.357	160 ± 111 *	0.26
without supplements		121 ± 70	0.631	128 ± 79 *	0.325	112 ± 55 *	0.22
Flavonoids (mg)		280 ± 163	0.458	269 ± 170	0.669	297 ± 151	0.571
Carotenoids (µg)		12624 ± 6414	0.581	12228 ± 6653	0.477	13176 ± 6051	0.819

[1] P-values indicate ability to predict concussion diagnosis from simple logistic regression

[A] denotes significant ($p<0.05$) predictor of delayed recovery football athletes and 100 mg/d for girls' soccer athletes, all of which were significantly ($p<0.05$) lower than both the recommendations for the general population and for concussion treatment (Table 2). Less than 50% of boys' football and girls' soccer athletes met the recommendations for magnesium, vitamin D, percent energy from added sugar, percent energy from saturated fat, and fiber intake (Figure 1). Poor diet quality for both boys' football and girls' soccer athletes was shown from the average percent energy from saturated fat, percent energy from added sugar, and the omega-6/omega-3 fatty acid ratio all being significantly ($p<0.05$) higher than published recommendations, while consumption of fiber and vitamin E were significantly ($p<0.05$) lower than recommended. Average magnesium was adequate ($p>0.05$), while zinc and vitamin C consumption was significantly higher than the published recommendations. Intakes of macronutrients were within the AMDRs; however, when compared to the g/kg recommendations for athletes, reported carbohydrate intake was significantly ($p<0.05$) lower (Table 2).

Prediction of Concussion Diagnosis

Using simple logistic regression, significant predictors of being diagnosed with a concussion injury in the overall population were identified to be percent energy intake from protein ($p=0.042$), percent energy intake from added sugar ($p=0.026$), and total zinc consumption ($p=0.017$) (Table 2). An inverse relationship with the concussion diagnosis outcome was seen with percent energy intake from protein (OR=0.17) and total zinc intake (OR=0.88), meaning that the odds of an athlete being diagnosed with a concussion decreased as percent of energy from protein and zinc intake increased. In contrast, there was a direct relationship between percent energy intake from added sugar and concussion diagnosis (OR=16493.00), meaning that athletes consuming a higher percentage of energy from added sugar had greater odds of being diagnosed with a concussion during the 2013 and 2014 fall sports seasons. The same relationships were seen in boy's football athletes between concussion diagnosis and the predictor variables of percent energy intake from protein (OR=0.82; $p=0.039$), total zinc consumption (OR=0.89; $p=0.048$), and percent energy intake from added sugar (OR=73032.00; $p=0.027$). DHA was not a significant predictor of concussion diagnosis in the overall population ($p=0.152$), boys' football athletes ($p=0.191$), or girls' soccer athletes ($p=0.473$) (Table 2). No significant ($p>0.05$)

relationships were found between the given nutrients or dietary components and concussion diagnosis in girls' soccer athletes (Table 2). The demographic variables of age and BMI were not significantly associated ($p>0.05$) with being diagnosed with a concussion injury in the overall population, boys' football, or girls' soccer athletes (Table 1). The predictor variables of sex, age, DHA intake, percent energy intake from protein, percent energy intake from added sugar, and zinc intake were used to build a multiple logistic regression model to predict the outcome of concussion diagnosis ($p=0.042$). After controlling for all other predictor variables, the only variable that still significantly ($p=0.040$) predicted concussion diagnosis was total zinc intake.

Demographic Characteristics of Athletes with Concussion Diagnosis

During the 2013 and 2014 fall sports seasons, 19 participants were diagnosed with concussion injuries, of which 13 were boys' football athletes and 6 were girls' soccer athletes. The demographic characteristics of the participants diagnosed with concussion injuries are shown in Table 3. The average age of all athletes with concussion diagnoses was 15.1 years, which was similar to the entire population. The average age for boys' football athletes with a concussion diagnosis was also similar to the entire population at 15.5 years, while girls' soccer athletes were younger in age at 14.2 years. The average BMI values for athletes diagnosed with a concussion injury were within the normal category (Table 3).

Dietary Adequacy of Athletes with Concussion Diagnosis

The proportion of boys' football and girls' soccer athletes diagnosed with a concussion injury meeting published recommendations for selected nutrients or dietary components is given in Figure 2, by total intake and intake without supplements, if available. The mean intake of the assessed nutrients or dietary components for the overall group, and additionally for boys' football and girls' soccer athletes with concussion diagnoses, are shown in Table 4 along with published recommendations, if available. The proportion of athletes diagnosed with a concussion injury meeting DHA intake recommendations was lower than the overall population, as none of these participants met either the general recommendation for healthy adults or the proposed recommendation for treatment of concussion injuries (Figure 2). The average intake of DHA for

Table 3. Overall and Sport-Specific Demographic Characteristics for Athletes Diagnosed with a Concussion Injury

	Overall (n=19)			Boys' Football (n=13)			Girl's Soccer (n=6)		
Variable	Mean ± SD	Spearman's rho [1]	P-value [2]	Mean ± SD	Spearman's rho [1]	P-value [2]	Mean ± SD	Spearman's rho [1]	P-value [2]
Age (yr)	15.1 ± 1.0	-0.349	0.851	15.5 ± 0.8	-0.321	ND	14.2 ± 0.8	0.2887	0.561
Height (m)	1.74 ± 0.09			1.79 ± 0.05			1.66 ± 0.10		
Weight (kg)	71.1 ± 13.8			75.9 ± 12.8			60.8 ± 10.5		
BMI (kg/m2)	23.3 ± 3.6	-0.318	0.733	23.7 ± 3.4	-0.145	0.27	22.3 ± 4.0	-0.7	0.662

[1] Spearman's rho represents the correlation coefficient between the variable and total length of recovery in days

[B] denotes significant (p<0.05) correlation

[2] P-values indicate ability to predict delayed recovery from simple logistic regression

[C] denotes significant (p<0.05) predictor of delayed recovery

Note: ND stands for not determined

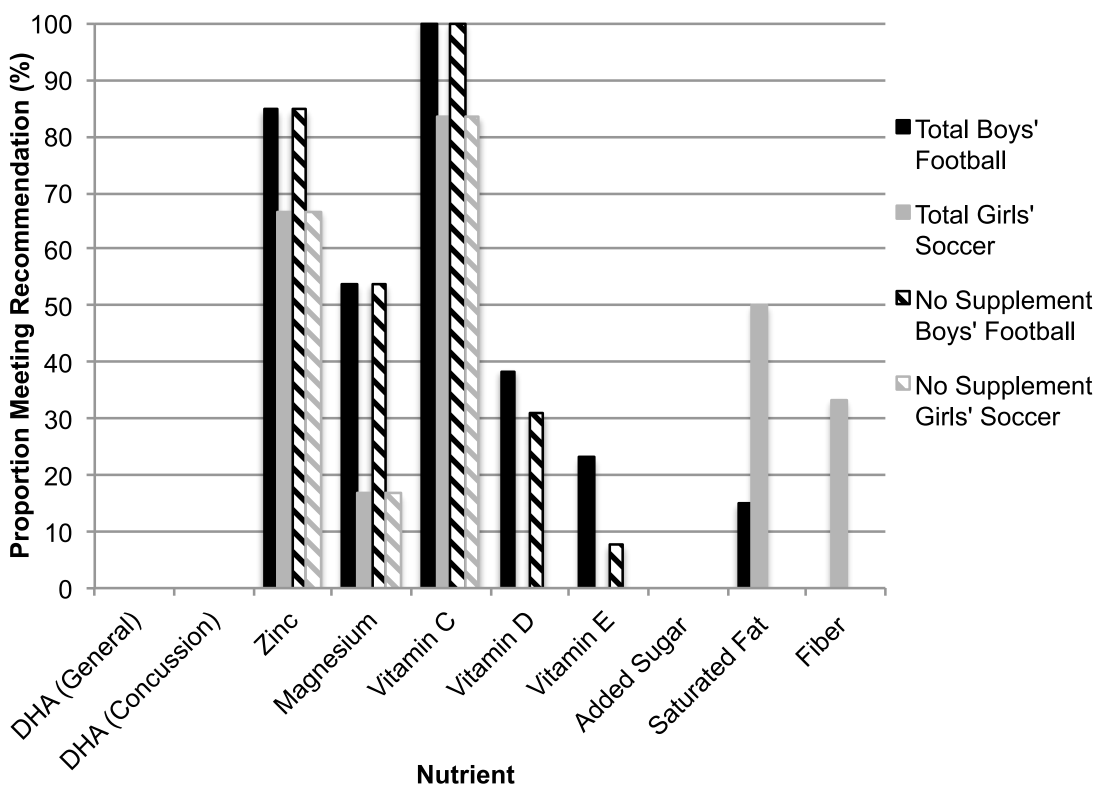

Figure 2. Proportion of Boys' Football and Girls' Soccer Athletes Diagnosed with a Concussion Injury Meeting Recommendations for Nutrient Intake With and Without Supplementation

Table 4. Overall and Sport-Specific Daily Macronutrient and Micronutrient Intake of Boys' Football and Girls' Soccer Athletes Diagnosed with a Concussion Injury

		Overall			Boys' Football			Girls' Soccer		
	Published Recommendation	Mean ± SD	Spearman's rho [1]	P-value [2]	Mean ± SD	Spearman's rho [1]	P-value [2]	Mean ± SD	Spearman's rho [1]	P-value [2]
Energy		2188 ± 942	− 0.052	0.087	2394 ± 1017	0.035	0.133	1740 ± 597	0.200	0.757
Carbohydrate (g)	130	299 ± 128	− 0.054	0.088	325 ± 140 *	0.004	0.146	242 ± 77 *	0.200	0.568
(g/kg)	6-10	4.3 ± 1.5	0.047	0.159	4.4 ± 1.7 *	0.004	0.102	4.0 ± 1.1 *	0.400	0.536
(% energy)	45-65	55 ± 5	0.241	0.341	55 ± 5	− 0.145	0.134	56 ± 5	0.300	0.264
Protein (g)	52 (males); 46 (females)	88 ± 37	− 0.123	0.139	95 ± 40 *	− 0.081	0.12	74 ± 27 *	0.100	0.435
(g/kg)	1.2-1.7	1.3 ± 0.5	0.041	0.418	1.3 ± 0.5	− 0.102	0.089	1.2 ± 0.5	0.300	0.214
(% energy)	10-30	16 ± 4	0.054	0.926	16 ± 4	0.057	0.186	17 ± 3	0.359	≤15 predicts data perfectly
Fat (g)	ND	73 ± 35	− 0.192	0.082	82 ± 37	− 0.032	0.148	55 ± 24	− 0.462	0.665
(% energy)	25-35	30 ± 3	− 0.46	0.29	30 ± 2	− 0.212	0.305	28 ± 4	− 0.8	0.921
Saturated Fat (g)		26 ± 13	− 0.223	0.066	29 ± 14	− 0.054	0.145	18 ± 9	− 0.6	0.545
(% energy)	<10%	10 ± 2	− 0.256	0.05	11 ± 2 *	0.088	0.139	10 ± 2 *	− 0.900 [A]	0.485
Trans Fat (g)	As little as possible	2.9 ± 1.5	− 0.187	0.125	3.4 ± 1.5	− 0.014	0.301	2.0 ± 0.8	− 0.224	0.447
DHA (mg)	250 (general); 387 (concussion)	74 ± 60	0.115	0.464	75 ± 59 *	0.034	0.764	70 ± 68 *	0.359	0.209
MUFA (g)		25 ± 12	− 0.183	0.091	28 ± 13	0.011	0.159	29 ± 9	− 0.6	0.649
Oleic Acid (g)		24 ± 11	− 0.183	0.091	26 ± 12	0.011	0.159	18 ± 8	− 0.6	0.638
PUFA (g)		15 ± 7	− 0.103	0.156	16 ± 7	0.025	0.176	12 ± 5	0.100	0.931
Omega-3 Fatty Acids (g)		1.5 ± 0.8	− 0.033	0.21	1.5 ± 0.8	0.014	0.2	1.3 ± 0.7	0.100	0.794
without supplements		1.5 ± 0.8	− 0.033	0.21	1.5 ± 0.8	0.014	0.2	1.3 ± 0.7	0.100	0.794
Omega-6:Omega-3 Ratio	1-2:1	9.3 ± 1.2	− 0.051	0.174	9.5:1 *	0.216	0.164	8.7:1 *	− 0.264	0.312
without suppelments		9.3 ± 1.2	− 0.051	0.174	9.5:1 *	0.216	0.164	8.7:1 *	− 0.264	0.312
Added Sugar (g)		84 ± 53	− 0.12	0.098	99 ± 57	0.039	0.268	52 ± 24	0.200	0.238
(% energy)	<10%	16 ± 7	− 0.191	0.893	18 ± 8 *	− 0.137	0.222	12 ± 4 *	0.100	>11% predicts data perfectly
Fiber (g)	38 (Males); 26 (Females)	19 ± 8	0.178	0.44	19 ± 8 *	0.133	0.215	20 ± 8	0.100	0.824
Zinc (mg)	8.5 (Males); 7.3 (Females)	11.3 ± 4.8	0.010	0.202	11.8 ± 5.2 *	0.023	0.154	10.0 ± 4.1	0.100	0.609
without supplements		11.3 ± 4.8	0.010	0.202	11.8 ± 5.2 *	0.023	0.154	10.0 ± 4.1	0.100	0.609
Magnesium (mg)	340	304 ± 127	− 0.111	0.228	316 ± 139	− 0.067	0.171	278 ± 104	0.100	0.794
without supplements		304 ± 127	− 0.111	0.228	316 ± 139	− 0.067	0.171	278 ± 104	0.100	0.794
Vitamin D (IU)	400	305 ± 226	− 0.066	0.136	359 ± 254	− 0.023	0.177	190 ± 70 *	0.500	0.995
without supplements		267 ± 186	− 0.066	0.178	303 ± 214	− 0.023	0.224	190 ± 70 *	0.500	0.995
Vitamin E (mg)	12	14.7 ± 22.1	0.043	0.231	18.4 ± 26.1	0.130	0.14	6.7 ± 3.0 *	0.100	0.617
without supplements		7.3 ± 2.9	− 0.016	0.284	7.5 ± 3.0 *	− 0.011	0.157	6.7 ± 3.0 *	0.100	0.617
Vitamin C (mg)	63 (Males); 56 (Females)	209 ± 158	0.039	0.179	209 ± 161 *	− 0.189	0.334	210 ± 168	0.200	0.508
without supplements		128 ± 88	− 0.15	0.304	148 ± 99 *	− 0.175	0.426	85 ± 34	0.200	0.979
Flavonoids (mg)		254 ± 141	0.311	0.971	250 ± 127	0.252	0.873	262 ± 181	0.400	0.98
Carotenoids (µg)		11843 ± 5213	0.106	0.982	10976 ± 4331	− 0.077	0.348	13721 ± 6828	0.300	0.663

[1] Spearman's rho represents the correlation coefficient between the variable and total length of recovery in days

[B] denotes significant (p<0.05) correlation

[2] P-values indicate ability to predict delayed recovery from simple logistic regression

[C] denotes significant (p<0.05) predictor of delayed recovery

* denotes significant (p<0.05) difference from published recommendations

all participants with a concussion diagnosis was 70 mg/d, while the average intake was 75 mg/d for boys' football athletes and 70 mg/d for girls' soccer athletes, all of which were significantly ($p<0.05$) lower than the recommendations for the both the general population and for concussion treatment (Table 4). However, DHA intake among athletes diagnosed with a concussion was not significantly different ($p>0.05$) than athletes without a concussion diagnosis for boys' football or girls' soccer. Less than 50% of boys' football and girls' soccer athletes with concussion diagnoses met the recommendations for vitamin D, vitamin E, percent energy from saturated fat, and fiber intake, while none of the athletes with a concussion diagnosis met the recommendation of less than 10% of energy intake from added sugar (Figure 2). Poor diet quality for both boys' football and girls' soccer athletes was shown from the average percent energy from saturated fat, percent energy from added sugar, and the omega-6/omega-3 ratio all being significantly ($p<0.05$) higher than published recommendations. The average percent energy intake from added sugar was significantly higher among athletes with concussion diagnoses overall ($p=0.019$) and for boys' football athletes ($p=0.015$), but not for girls' soccer athletes ($p=0.882$). Boys' football athletes with a concussion diagnosis had significantly ($p<0.05$) lower fiber and significantly ($p<0.05$) higher vitamin C and zinc intakes than recommended, while girls' soccer athletes with a concussion diagnosis consumed significantly ($p<0.05$) less vitamin D and vitamin E than the published recommendations. Intakes of macronutrients were within the AMDRs; however, carbohydrate intake was significantly ($p<0.05$) lower than the recommendations in g/kg for athletes (Table 4).

Relationship to Total Length of Recovery

Total length of recovery was determined for each athlete with a concussion diagnosis by counting the number of days from the diagnosis to completion of the graduated return to play protocol. Spearman's correlations were used to assess the relationship between total length of recovery and each demographic variable or dietary component. The demographic variables of age and BMI were not significantly associated ($p>0.05$) with total length of recovery. No significant associations ($p>0.05$) were found between any of the nutrients or dietary components and total length of recovery among all athletes diagnosed with a concussion or among boys' football athletes with a concussion diagnosis. There was a significant inverse association (rho=-0.90; p=0.0374) between percent energy intake from saturated fat and total length of recovery for girls' soccer athletes diagnosed with a concussion injury (Table 4).

Prediction of Delayed Recovery

Delayed recovery was defined as taking longer than five days to complete the graduated return to play protocol. Simple logistic regression was used to assess the ability of demographic characteristics and dietary components to predict a delayed recovery. No significant (p>0.05) predictors were identified from the demographic variables (Table 3) or nutrients (Table 4) assessed. However, all the girls' soccer athletes diagnosed with a concussion injury consumed less than 15% of energy intake from protein and greater than 11% energy intake from added sugar (Table 4).

Concussion Recurrence

No participants were diagnosed with a recurrent concussion within the same sports season, so no analyses were performed for concussion recurrence.

Dietary Supplement Use

The proportion of boys' football and girls' soccer athletes taking dietary supplements, of both the total participants and athletes diagnosed with a concussion injury, are given in Figure 3. The overall proportion of all athletes taking a dietary supplement was determined to be 42.9%, while the proportion of athletes diagnosed with a concussion injury taking a dietary supplement was 42.1%. A greater proportion of girls' soccer athletes reported taking a dietary supplement when compared to boys' football athletes. No athletes diagnosed with a concussion injury reported taking a fish oil supplement. Multivitamins, vitamin E, and vitamin D supplements were also not reported by any girls' soccer athletes with a concussion diagnosis (Figure 3).

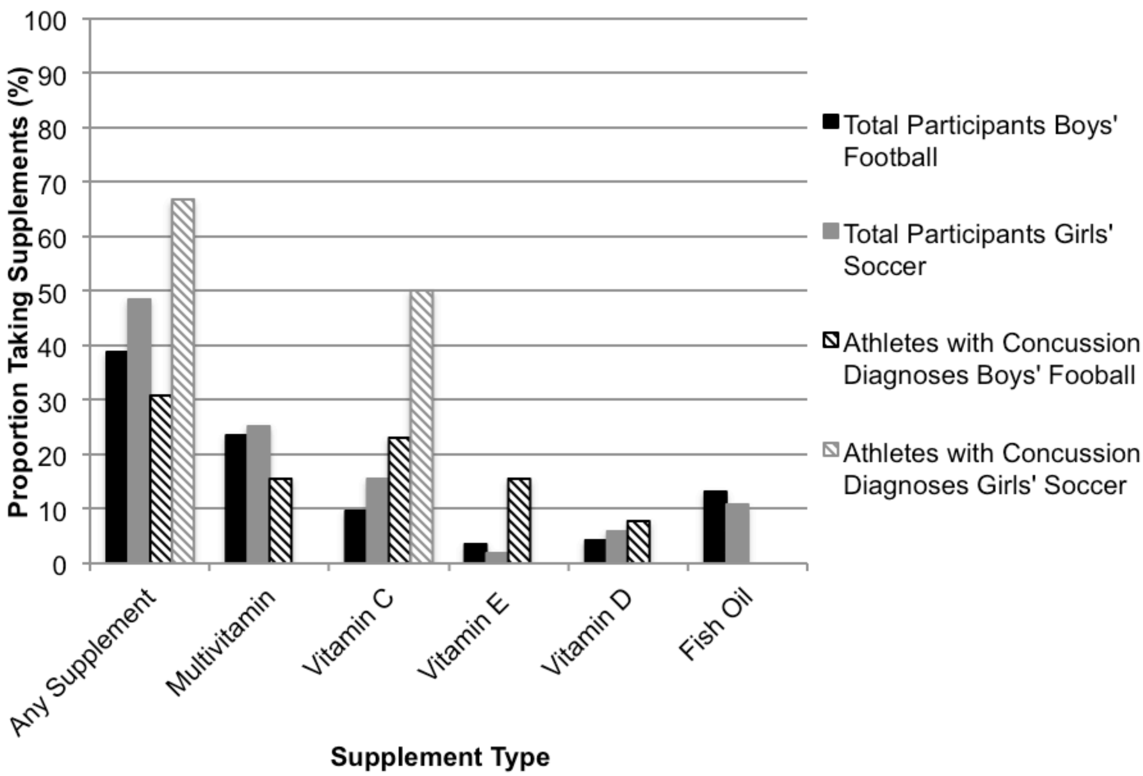

Figure 3. Proportion of Sport-Specific Total Participants and Athletes Diagnosed with a Concussion Taking Dietary Supplements

DISCUSSION

The overall concussion incidence rate for boys' football and girls' soccer athletes (0.70 per 1000 athletic exposures) over the 2013 and 2014 fall sports seasons in this study was significantly ($p=0.005$) higher than previously reported high school concussion rates of 0.24 and 0.25 per 1000 athletic exposures (3, 4). This finding could have been due to the exclusion of sports other than football and soccer in the current study to calculate overall concussion rates. When comparing sport-specific concussion incidence rates to previously reported rates (4), no significant differences were found for boys' football (0.78 per 1000 athletic exposures; $p=0.394$) or girls' soccer (0.59 per 1000 athletic exposures; $p=0.304$) athletes. These results indicate that the concussion incidence rates among boys' football and girls' soccer athletes in three high schools across the Salt Lake Valley over the 2013 and 2014 fall sports seasons were similar to other high school populations in the United States.

Overall dietary quality among the high school athlete participants in this study was shown to be poor with low intake of many important nutrients including DHA, fiber, vitamin D, and vitamin E as well as high intakes of saturated fat, trans fat, added sugar, and a high omega-6/omega-3 fatty acid ratio. These results indicate a need for education and dietary intervention in the adolescent athlete population in order to improve overall health, sport performance, and possibly concussion outcomes. In the current study, percent energy intake from protein, percent energy intake from added sugar, and total zinc consumption was shown to be significantly ($p<0.05$) associated with the risk of sustaining a concussion injury in the overall population and among boys' football athletes. Furthermore, when controlling for sex, age, DHA intake, percent energy intake from protein, and percent energy intake from added sugar, zinc continued to be a significant predictor ($p=0.040$) of concussion incidence, with the odds of being diagnosed with a concussion injury decreasing as zinc consumption increased. Interestingly, there was an unexpected significant inverse correlation in girls' soccer athletes between the percent energy intake from saturated fat and the total length of recovery, that as percent energy intake from saturated fat decreased, total length of recovery increased. These unexpected results could have been due to a small sample size (n=6) of girls' soccer athletes diagnosed with a concussion injury (n=6), and only 50% of these participants were meeting the recommendations of less than 10% of total energy intake being consumed as saturated fat.

Contrary to the hypothesis, no significant ($p>0.05$) relationships were identified between DHA intake and the outcomes of concussion incidence, total length of recovery, or delayed recovery. These results are likely due to overall poor intake of DHA among the study population, as less than 10% of the entire population and 0% of athletes diagnosed with a concussion injury were meeting either the dietary recommendation for the general population or for concussion treatment. With this overall inadequate dietary intake of DHA, detecting a change and significant relationship with the outcome is difficult. The overall low dietary intake of DHA in this population, along with the information gathered on supplement usage among boys' football and girls' soccer athletes in this study, was interesting and applicable to future research. While only 13.2% and 10.7% of all boys' football and girls' soccer athletes, respectively, were specifically taking a fish oil supplement, a surprisingly high proportion of boys' football (38.9%) and girls' soccer (48.5%) athletes were habitually taking some type of supplement. These results support the need for DHA supplementation studies in relation to concussion incidence and recovery, as many athletes are already taking supplements of some kind and a supplementation study would create more variation in DHA intake levels to help reach statistically significant results.

The strengths of this study included the longitudinal prospective design, the adolescent human subject population, and also the ability to objectively assess concussion incidence and recovery. This study assessed the relationship between habitual dietary intake of various nutrients and the future risk of being diagnosed with a concussion injury, as well as the severity of the concussion injury as assessed by the length of the recovery. To our knowledge, this is the first study on this topic conducted with an adolescent athlete human population, which has been identified as a population of concern for recurrent sports-related concussive or sub-concussive injuries resulting in potential long-term effects on cognition and behavior. Many of the previous human studies evaluating the effect of DHA intake on concussion incidence or outcomes have been epidemiological studies, which rely on the self-reported number of concussion injuries. In this study, documentation from the TOSH Concussion Clinic and the ATCs assigned to each school were used to gather data on concussion incidence and recovery. This documentation allowed for a more objective evaluation of concussion injuries, as these personnel were trained in the diagnosis of concussions and followed a set protocol for making return to play decisions.

The weaknesses of this study include a small sample size, use of a food frequency questionnaire to quantify habitual nutrient intake, and the lack of laboratory measurements of DHA status. The small sample size for the overall population (n=247) and for athletes diagnosed with concussion injuries (n=19), as well as poor dietary intake among the participants, made it difficult to find significant relationships between dietary intake, specifically DHA intake, and concussion incidence or recovery. Habitual dietary intake was assessed in this study using the YAQ, which is a food frequency questionnaire developed for the adolescent population. Potential problems with any food frequency questionnaire include misreporting, difficulty recalling the frequency of consuming specific foods, and the inability of the questionnaire to capture all types of food consumed by different individuals. Although these are all potential sources of error, the YAQ has been shown to be a reliable tool to assess the dietary intake of the adolescent population (38). DHA intake from the YAQ in this study was also assumed to accurately reflect overall DHA status in tissues. Although DHA status was not directly assessed using blood testing, previous research has shown a strong correlation between dietary intake and levels of DHA in the body (46, 47), suggesting that dietary intake reflects overall DHA status.

To our knowledge, this is the first study to evaluate the dietary adequacy of various nutrients, including DHA, among the adolescent athlete population. Given the high risk of concussion injury in this population, along with the potential benefit of DHA and other nutrient intakes on reducing the severity of concussion injuries and possible long-term effects, it was important to identify potential nutrient deficiencies and areas of intervention. The dietary intake information from this study, and the identified relationship between markers of overall low dietary quality like high intake of added sugar and risk concussion diagnosis, could provide a foundation for future research and intervention within the adolescent athlete population. Future research should focus on dietary intervention trials and clinical trials with DHA supplementation before and after concussion injuries in this population to identify strategies for decreasing concussion incidence among adolescent athletes and a potential method of active treatment.

CONCLUSION

In this longitudinal prospective study, the overall dietary quality among adolescent athletes was shown to be poor with a high intake of saturated fat, trans fat, added sugar, and a high omega-6/omega-3 fatty acid ratio, as well as a low intake of DHA, fiber, vitamin D, and vitamin E, which are dietary patterns that have been associated with increased inflammation, oxidative stress, and poor health (31-36). These results indicate a need for dietary intervention and education among this population, as well as parents/guardians, in order to improve the dietary quality for sport performance, prevention and treatment of concussion injuries, and life-long health. Further research with larger sample sizes and dietary intervention or supplementation components need to be done to fully investigate the potential effect of dietary intake of DHA on concussion incidence and outcomes. Due to inadequate intake of DHA from dietary sources in this population and the high proportion of dietary supplement use, DHA supplementation may be a potential strategy to increase intake and improve concussion outcomes if positive treatment effects of DHA on concussion injuries can be identified in future studies.

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