Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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KEY WORDS

Rugby; neck, injury, strength

WORD COUNT

2665

ABSTRACT

Objectives: To compare the cervical isometric strength, fatigue endurance and range of motion of adult and under-18 age grade front row rugby players to inform the development of a safe age group policy with particular reference to scrummaging.

Design: Cross-sectional cohort study.

Setting: 'Field testing' at Murrayfield stadium.

Participants: 30 high performance under-18 players and 21 adult front row rugby players

Outcome measures: Isometric neck strength, height, weight and grip strength.

Results: Youth players demonstrated the same height and grip strength as the adult players; however the adults were significantly heavier and demonstrated substantially greater isometric strength ($p < 0.001$). Only 2 of the 'elite' younger players could match the adult mean cervical isometric strength value. In contrast to school age players in general, grip strength was poorly associated with neck strength (r=0.2) in front row players; instead player weight (r=0.4) and the number of years' experience of playing in the front row (r=0.5) were the only relevant factor in multivariate modelling of cervical strength (R^2=0.3).

Conclusions: Extreme forces are generated between opposing front rows in the scrum and avoidance of mismatch is important if the risk of injury is to be minimised. Although elite youth front row rugby players demonstrate the same peripheral strength as their adult counterparts on grip testing, the adults demonstrate significantly greater cervical strength. If older youths and adults are to play together, such findings have to be noted in the development of age group policies with particular reference to the scrum.

ARTICLE SUMMARY

Key Findings

Front row rugby players under the age of 18 cannot resist the same cervical loads as adult front row players.

In contrast to general findings on youth players, predictive modelling of cervical strength by proxy measures in this specific group is poor and direct testing is required.

This is directly relevant to age related playing policy for under-18s competing in the front row in the adult game as appropriate neck strength is paramount to preventing scrum collapse and the associated injuries.

Age related playing policy should reflect both generic and position specific physical ability

Strengths and Limitations

A particular strength of this study is the direct physical cervical testing of representative player cohorts, and the novel data presented.

A limitation is the assumed though unsubstantiated link between cervical strength and injury; though this is mitigated in this specific context through the known link between scrum collapse and cervical injury.

INTRODUCTION

Rugby is the world's most popular contact, or more appropriately collision, sport and carries an injury risk four times greater than semi-contact sports such as football/soccer.[1] The scrum is an iconic and fundamental part of the game, where two 'forward packs' compete for the ball to restart the game following a minor infringement. It is a test of strength and technique where the cervical spine of the opposing front rows are subjected to huge compressive and shear forces of a sufficient magnitude to result in tissue injury[2] and structural failure.

Around 8% of all injuries in professional rugby are thought to result from the scrum,[3, 4] and rates in amateur and youth rugby are thought to be similarly proportioned. Though this number is comparatively small, these injuries are likely to be of greater severity and involve the spine.[5] Despite a typical match consisting of comparatively few scrums (compared to other contact events, such as tackles), around 40% of all rugby derived acute spinal cord injuries occur in the scrum.[6, 7] Scrum engagement occurs as the head and shoulders of the competing front rows make forceful contact. This is thought to be a particular risk factor for injury, through high compressive and shear loads or hyperflexion of the cervical spine.[6-8] This risk has been somewhat mitigated in recent years by the introduction of 'controlled scrum engagement' where the distance between opposing front rows has been standardised in attempt to reduce acceleration and thus collision forces.[9, 10] Collapsing of the scrum has also been identified as a leading cause of scrum related injury.[6] Premature micro trauma induced degeneration of the cervical spine in front row players[11] and mismatches in size between front row players[6, 12] have been suggested as potential factors for the over-representation of scrum-related injuries, though Brown et al.[7] note that coaching and technical factors have not been well explored in these analyses.

Body size and physical mismatch are considered (at least in part) to be associated to injury risk in schoolboy rugby.[13] Some national governing bodies have introduced a weight category banding for youth rugby to address this concern in children who mature skeletally at differing rates. However once players reach the age of 18 all participants are considered as adults and no such segregation takes place, indeed rugby is a sport that relies on differing physical attributes for the various playing positions. There are circumstances though where those yet to reach their 18th birthday may wish to play adult rugby, either through selection processes in the case of particularly gifted players, or through leaving school and joining a club playing in the adult leagues. Policy within Scottish Rugby (prior to the start of the 2013-2014 season) had been that only 'exceptional' 17 year-old players were eligible to play in the adult leagues however there was concern as to the suitability of this policy regarding the front row.

The scrum exposes player's cervical spines to potentially injurious forces that must be attenuated by controlled spinal motion through the cervical musculature, ligaments and inter-vertebral discs.[14] Appropriate strength of the cervical musculature is thus particularly important for front row players. We have previously demonstrated large variation in the neck strength of school-aged rugby players,[15] however we are not aware of any report of data specific to the front row forwards (either youth or adult).

The aim of this study was to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players to assess the ability of under18 players to compete with adults in the front row of the scrum. A secondary objective was to assess the relationship between isometric strength, and various other physical parameters previously shown to predict this.

METHODS

Study design and population

A cross-sectional cohort study was undertaken to investigate the isometric neck strength and fatigue endurance of front row rugby players. 30 senior school-aged players (under-18 age-grade) were assessed at a Scottish Rugby Union (SRU) training day, and 22 adult players in a separate assessment, again organised in conjunction with the SRU.

The youth players were drawn from 21 different clubs/schools from across Scotland and represented the 'elite' end of the senior school-aged front row players in Scotland. The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams. Both adult and school-age testing sessions took place at the same facility in Murrayfield stadium in the same environment using the same equipment and operators. Participation was voluntary and signed consent was obtained from all participants. Regional Ethics Committee approval was received for this study.

Cervical strength and endurance assessment

Isometric cervical muscle testing is well validated.[16-18] We assessed maximal voluntary isometric cervical muscle strength with the GS Gatherer and GS Analysis Suite (Gatherer Systems Ltd, Aylesbury); a custom-built device based on a 300Kg load cell and bespoke software system.

The test was performed employing a previously reported protocol[15, 19] where the head was placed in the neutral anatomic position and subjected to manual controlled incremental loading to positional failure (the point of head movement). Subject report of pain or neurological symptoms also stopped the test. Loading was applied and data was recorded at 20Hz. Peak isometric force generated by the musculature was defined as the maximal load recorded during the test procedure. An average of 3 tests is reported.

An assessment of cervical musculature fatigue endurance was made using the same test equipment. The player was required to exert an isometric extension load at 50% of their recorded mean peak extension force for as long as possible. The player sat in a neutral position with their arms by their side and head connected to the load cell. Players received visual graphical feedback as to the target load applied via a computer monitor. This allowed for maintenance of a consistent load until failure. A single assessment was made of fatigue.

Anthropometric parameters

Additional measures were made of; height (Leicester Height Measure; SECA, UK), weight (medical grade mechanical flat scales; SECA, UK), grip strength (JAMAR hydraulic hand dynamometer; Sammoms Preston, Illinois, USA) and cervical range of motion (Cervical Range of Motion Instrument, Performance Attainment Associates, Minnesota, USA). 3 readings were obtained for each parameter and their average was derived and reported. Demographic data and a self-report questionnaire to determine the individual's rugby playing history and details of neck specific training and injuries were completed by the participants prior to physical assessment.

Data analysis

Data were analysed using Minitab (Version 16). Data were checked for normality and are reported as means with standard deviation as a measure of dispersion. Independent samples t-tests were used to assess differences in continuous variables between groups unless otherwise stated. Significance was accepted as $p < 0.05$ incorporating the Benjami-Hochberg correction for the testing of multiple hypotheses, to reduce the possibility of making a type II error in the interpretation of results.[20, 21] Pearson correlation coefficients are reported for bivariate correlations. Pearson correlation coefficients are reported for bivariate correlations. Multivariate stepwise regression modelling was performed to achieve the most predictive model utilising the fewest variables. Predictive variables were selected with a significance of $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables was controlled.

RESULTS

As expected, large differences were observed between groups in terms of age and experience (years) playing as a front row forward. There was no difference in height or grip strength between the groups, though the adults were significantly heavier. Cervical range of motion was similar in measures of extension and rotation, though the elite under-18 group had a greater range of cervical flexion and rotation (table 1).

Substantial differences were observed in isometric strength between groups in extension (figure 1, table 2) and side flexion (table 2). A larger variation was seen in all parameters of adult neck strength data compared to the under 18 group. This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data, only 2 of the 30 elite under-18 front row players achieved the adult mean strength value (figure 2).

Only 3 of the under-18s achieved the adult mean isometric extension fatigue endurance (total work, figure 1), this difference between groups was significant at $p < 0.1$, possibly reflecting the large variation in adult scores. The adults performed better in the fatigue assessment, holding significantly higher average loads for the same length of time as the younger players (table 2). Surprisingly, only a quarter of all players reported performing routine neck exercises; split evenly between groups (table 1).

Isometric neck strength was most associated with the experience of playing in the front row (r=0.5) (Figure 2), followed by weight (r=0.4) and player age (r=0.4). In contrast, grip strength correlated relatively poorly (r=0.2) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly (r=0.30). Player weight (r=0.6) was the factor most associated with fatigue, again grip strength correlated poorly (r=0.1).

Multivariate regression found the best predictive model for isometric strength to include the number of years' experience playing in the front row and the players' weight (table 3). The same variables also created the best predictive model of fatigue endurance, again explaining around a third of the variation in neck strength (R^2=0.4).

DISCUSSION

This study demonstrates that even elite under-18 front row rugby players, who have participated in a conditioning and strengthening programme, are able to generate significantly less cervical muscle force than their adult equivalents. This is highly relevant in determining the suitability of such players to compete in the adult game, where significant forces are exerted through the cervical spine of the front row forwards during the scrum. These forces must be modulated by the cervical musculature, and the reduced isometric strength and fatigue endurance ratings found in the under-18 players puts them at a significant disadvantage, with potentially injurious consequences. A particular concern is that the under-18 players evaluated in this study contained a selection bias of high performance age-grade players. While this group represents the players most likely to be considered appropriate to play in the adult leagues, it is also likely that they are bigger and stronger than their age-grade counterparts, suggesting that the actual difference between the adult and under-18 values in the wider population may be much greater.

Little information is available as to the 'neck strength' of rugby players, either adult or school-aged. We previously assessed the cervical isometric strength of Scottish school children between the ages of 13 and 18 and found huge variation both within and between year groups.[15] We are not aware of any other comparable data for adult players or of any study specifically investigating the cervical isometric strength of the front row forwards. Using multivariate techniques, we previously reported that player age, weight and grip strength (as an objective measure of overall strength) was strongly predictive of isometric neck extension strength in the general school-aged rugby playing population; explaining around two thirds of the variance in cervical strength. Interestingly in this analysis, the measure of grip strength was not a strong predictor of cervical strength in this specific group of front-row players, where player weight and number of years of experience of playing in the front row were the most important factors. This finding may be a reflection of the general lack of neck specific training performed among rugby players. It is likely that for most people scrummaging is the main source of cervical strength training and this is supported by the finding that only a quarter of the players assessed reported performing regular exercises for the neck. We propose that the elite under-18 players had reached the same global strength as their adult counterparts through peripheral strength training; however in the absence of specific structured conditioning, they could not match the cervical strength the adults had gained as a result of years of competitive scrummaging.

This is to our knowledge the first report of a cervical musculature fatigue endurance assessment in front row rugby players of any age. In the absence of previous data, it was necessary to set a safe threshold at which to perform the test, thus the 50% sub-maximal value was selected to determine reference values for adult and under-18 front row players. While large differences were observed in fatigue endurance values achieved between adult and under-18 players, the large spread of the data in the adult cohort diluted the significance of this finding. Though all players achieved a similar time on fatigue assessment, the 50% sub-maximal load held by the under-18 group (20kg equivalent) was significantly less than the adult 50% load (25kg equivalent), as a result of their lower peak forces on the maximal isometric testing. Now that these benchmark data are available, we recommend that future fatigue endurance assessment of under-18 players should be performed using the mean adult 50% sub-maximal value (25Kg equivalent), which would represent around 60% of the average under-18 maximal isometric value found in this study. It is likely that greater differences would be apparent between adults and under-18 groups had we been able to employ this testing design, and further help discern those able to compete in the adult front row. Future work should also look at assessing 'scrum-specific' fatigue endurance; looking perhaps at repeated bouts of 80% sub-maximal testing over 10-15 seconds which better reflects the demands of this activity.

Preatoni et al.[2] assessed the forces generated in the scrum by 34 forward packs at 6 different playing grades (from senior-school to international level) and found notable differences in the forces generated between schools and senior sides. Worryingly, these authors further reported that the combined compression and shear forces they recorded in the scrums were of a sufficient magnitude to induce chronic spine injury. Though further information is needed to understand the link between mechanical forces in the scrum and injury, the shear forces recorded are of particular concern as a risk factor for chronic degeneration of the spine through undesirable rotation and bending motions.

Perhaps of greater concern is the closed kinetic chain situation of the scrum; where the head is constrained from moving and loads are applied at both ends. This can lead to a bucking motion; a process particularly evident in front row forwards when the scrum collapses and the head strikes the ground. If any single front row player has weak cervical extensors, it is reasonable to suggest that this may enhance the risk of scrum collapse. For the safety of all six front row players, it is important to recognize, understand and mitigate the biomechanical issues that occur in a closed kinetic chain situation where the forces cannot be vectored away from the spine.

In the elite under-18 group assessed, only 2 of 30 players recorded the mean cervical isometric strength of the adult cohort. Although a few individuals may possess the physical characteristics (and technical skill) to compete with adult players, our results suggest that policy should prevent players under the age of 18 playing in the front row of an adult match, unless specific criteria is met. In contrast to the general schoolboy population, predictive modelling of cervical strength using alternative physical characteristics was poor. As such, specific testing would need to be employed to identify those few individuals able to match their adult counterparts in terms of cervical strength. The concept of a passport to play in the front row is well established in some countries as a means of ensuring players are appropriately equipped to cope with the rigours of scrummaging. Objective measures of the individuals' cervical strength profile should be an integral part of any selection process for players wishing to play in the front row.

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AUTHOR CONTRIBUTIONS

All authors listed were involved in the study design and data acquisition. DH performed the analysis and drafted the manuscript. All authors revised and approved the submission.

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CONFLICT OF INTEREST

DG has shares in Gatherer Systems who manufacture and supplied the testing equipment used in this study. The other authors declare no conflict of interest.

DATA SHARING STATEMENT

The data are held in a secure database at the University of Edinburgh. Any party wishing to access unpublished data should discuss with the corresponding author in the first instance.

REFERENCES

[1]. Palmer-Green DS, Stokes KA, Fuller CW, et al. Match injuries in English youth academy and schools rugby union: an epidemiological study. *Am J Sports Med*. 2013;41:749-55.

[2]. Preatoni E, Stokes KA, England ME, et al. The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scand J Med Sci Sports* 2013;23:178-184

[3]. Brooks JHM, Fuller CW, Kemp SPT, et al. Epidemiology of injuries in English Professional rugby union: part 1 match injuries. *Br J Sports Med* 2005:39:757-766

[4]. Brooks JHM, Fuller CW, Kemp SPT,et al. Epidemiology of injuries in English Professional rugby union: part 2 training injuries. *Br J Sports Med* 2005:39:767-775

[5]. MacLean JG, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great Britain and Ireland. *Br J Sports Med* 2012;46:591-4.

[6]. Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and spinal cord. *Sports Med* 2002;32:633-53

[7]. Brown JC, lambert MI, Verhagen E, et al. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohrot study. BMJ open 2013;3:e002475

[8]. Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players *Br J Sports Med* 2011;45:765–775.

[9]. Gianotti S, Hume PA, Hopkins WG, et al. Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *Br J Sports Med* 2013;42:427-430

[10]. Fuller CW, Brooks JH, Kemp SP. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med*. 2007;17:10-6

[11]. Scher AT. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clin Sports Med*. 1998;17:195-206

[12]. Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med*. 2012;46:692-3

[13]. Nutton RW, Hamilton DF, Hutchison JD, et al. Variation in physical development in schoolboy rugby players: can maturity testing reduce mismatch? *BMJ Open*. 2012;2:e001149

[14]. Torg J, Ramsey-Emrhein J. Suggested management guidelines for participation in collision activities with congenital, developmental, or post injury lesions involving the cervical spine. *Med Sci Sports Exerc*, 1997;29(7):256–272.

[15]. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A CROSS-SECTIONAL COHORT STUDY OF SCOTTISH SCHOOLCHILDREN. *Bone Joint Res* 2012;1:152–7.

[16]. Garge´s GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc* 2002;33:464-70.

[17]. Jordan A, Mehlsen J, Bu¨low PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine* 1999;24:1343-8.

[18]. Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil* 2002;16:851-8.

[19]. Peek K, Gatherer D. The rehabilitation of a professional rugby union player following a C7/T1 posterior microdiscectomy. *Phys Ther Sport* 2005;**6**:195–200.

[20]. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Statist. Soc.* B 1995;**57**, 289–300.

[21]. Storey JD, "The positive false discovery rate: A Bayesian interpretation and the q-value" *Annals of Statistics* 2003;31: 2013–2035

TABLES

Table 1- Anthropometric data

	Under 18	Adult	Significance
Age (years)	16.7 (16-17)	27.2 (19-50)	<0.001‡
Experience of the front row (years)	5.0 (1-12)	14.3 (2-26)	<0.001‡
Regular neck strengthening (yes/no)	7/23	5/21	0.959*
Height (cm)	178.7 (5.54)	178.7 (5.91)	0.960
Weight (kg)	96.0 (13.69)	107.8 (13.67)	0.004‡
Grip strength (kg)	47.8 (5.31)	49.56 (7.56)	0.360
Cervical Range of Motion (degrees)			
Extension	65.33 (8.70)	65.62 (6.62)	0.895
Flexion	58.50 (8.32)	44.10 (8.93)	<0001‡
Side flexion (left)	49.17 (5.88)	44.33 (6.51)	0.010‡
Side flexion (right)	45.60 (8.93)	41.33 (6.18)	0.049
Rotation (left)	66.50 (7.67)	65.90 (6.80)	0.772
Rotation (right)	67.83 (8.06)	64.76 (6.83)	0.149

Age and experience reported as mean (range), all other variables as mean (SD); ‡ Remains significant at the 0.05 level correcting for multiple testing; *Chi Square

Table 2 - Cervical strength assessment

	Under 18	Adult	Significance
Isometric Strength (kg)			
Extension	41.70 (6.74)	53.70 (12.36)	<0.001‡
Flexion	22.59 (5.96)	25.40 (5.76)	0.098
Side flexion (left)	32.24 (6.16)	40.53 (9.76)	0.002‡
Side flexion (right)	31.83 (6.08)	42.48 (7.59)	<0.001‡
Fatigue			
Total (kg/sec)	1305 (236.8)	1551 (512)	0.058
Time achieved (sec)	67.10 (21.67)	71.81 (9.73)	0.390
Average load (kg)	18.25 (2.82)	23.54 (5.13)	<0.001‡

All data reported as mean (SD). ‡ Remains significant at the 0.05 level correcting for multiple testing

Table 3 – Multivariate predictive modelling of isometric neck extension (R^2=0.31)

Predictor	Co-efficient	P value
Front row experience	0.63	0.035
Weight	0.22	0.003

FIGURE LEGEND

Figure 1 - Differences in cervical strength by group

Figure 2 – Strong relationship between cervical strength and playing experience

Figure 3 – Weak relationship between grip strength and cervical strength

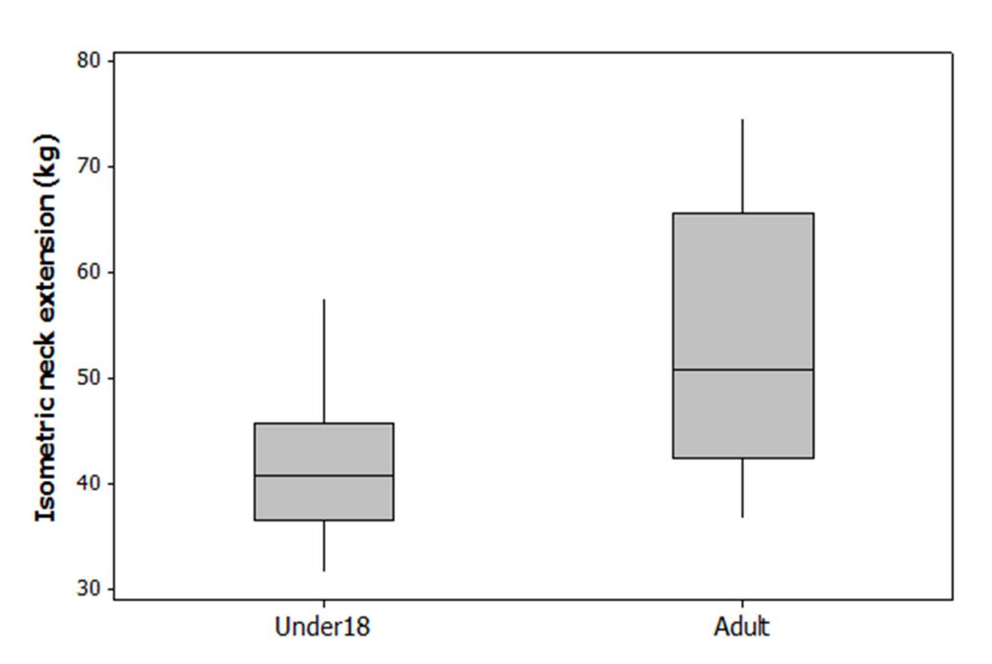

Figure 1 - Differences in cervical strength by group
152x101mm (96 x 96 DPI)

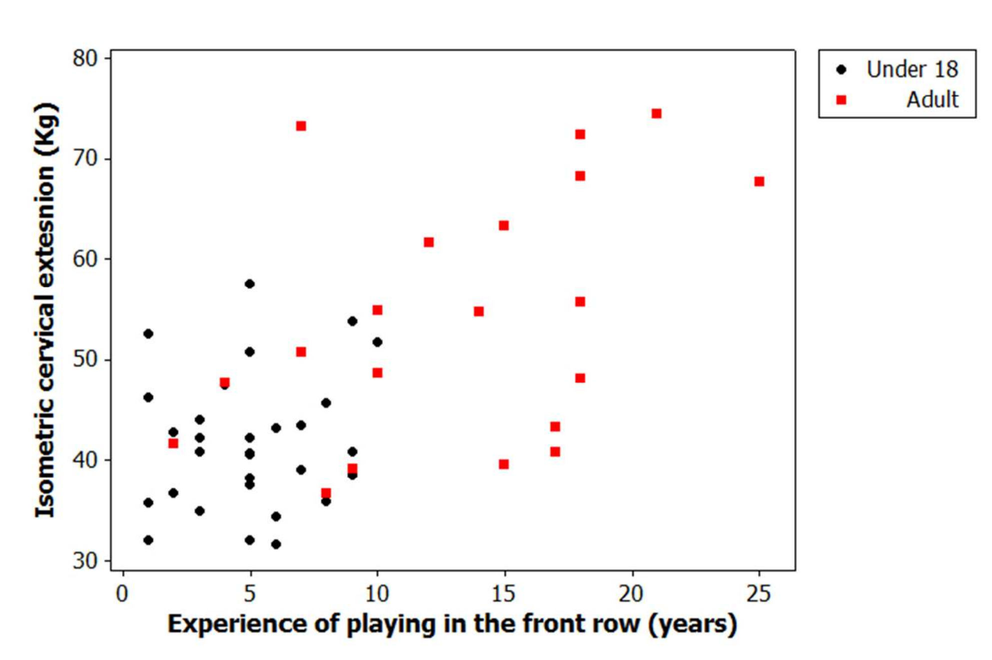

Figure 2 - strong relationship between cervical strength and playing experience
190x127mm (96 x 96 DPI)

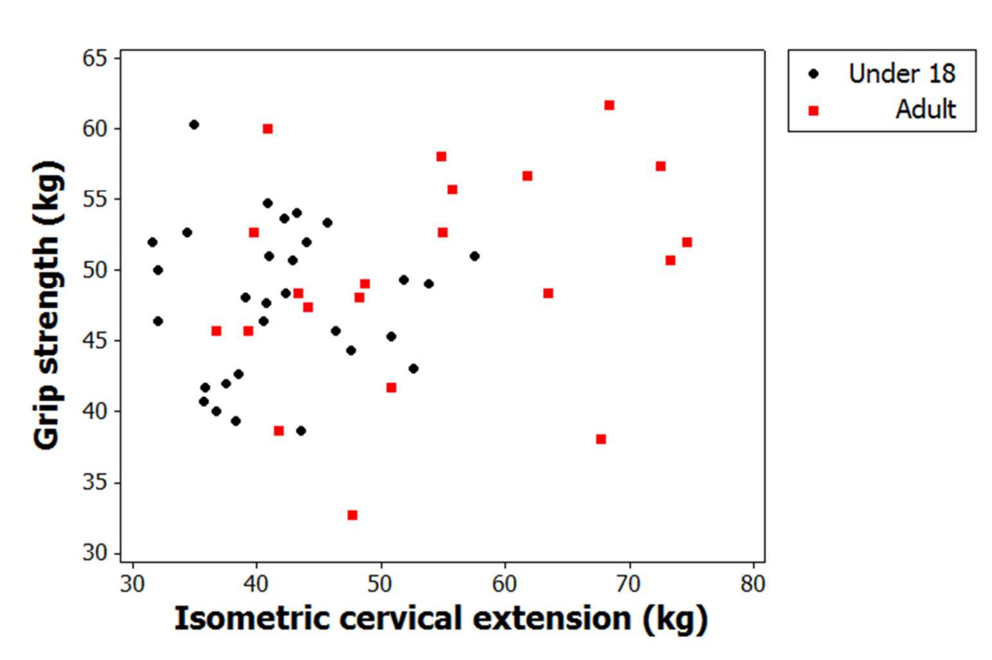

Figure 3 - Weak relationship between grip strength and cervical strength
190x127mm (96 x 96 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3,4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	4
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	4
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	4
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	4
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	4
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	5
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	6, 7, 8
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	6, 7, 8
Generalisability	21	Discuss the generalisability (external validity) of the study results	8, 9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	9

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

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KEY WORDS

Rugby; neck, injury, strength

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ABSTRACT

Objectives: To compare the cervical isometric strength, fatigue endurance and range of motion of adult and under-18 age grade front row rugby players to inform the development of a safe age group policy with particular reference to scrummaging.

Design: Cross-sectional cohort study.

Setting: 'Field testing' at Murrayfield stadium.

Participants: 30 high performance under-18 players and 21 adult front row rugby players

Outcome measures: Isometric neck strength, height, weight and grip strength.

Results: Youth players demonstrated the same height and grip strength as the adult players; however the adults were significantly heavier and demonstrated substantially greater isometric strength ($p < 0.001$). Only 2 of the 'elite' younger players could match the adult mean cervical isometric strength value. In contrast to school age players in general, grip strength was poorly associated with neck strength ($r=0.2$) in front row players; instead player weight ($r=0.4$) and the number of years' experience of playing in the front row ($r=0.5$) were the only relevant factor in multivariate modelling of cervical strength ($R^2=0.3$).

Conclusions: Extreme forces are generated between opposing front rows in the scrum and avoidance of mismatch is important if the risk of injury is to be minimised. Although elite youth front row rugby players demonstrate the same peripheral strength as their adult counterparts on grip testing, the adults demonstrate significantly greater cervical strength. If older youths and adults are to play together, such findings have to be noted in the development of age group policies with particular reference to the scrum.

ARTICLE SUMMARY

Key Findings

Front row rugby players under the age of 18 cannot resist the same cervical loads as adult front row players.

In contrast to general findings on youth players, predictive modelling of cervical strength by proxy measures in this specific group is poor and direct testing is required.

This is directly relevant to age related playing policy for under-18s competing in the front row in the adult game as appropriate neck strength is likely to be important in preventing scrum collapse and the associated injuries.

Age related playing policy should reflect both generic and position specific physical ability

Strengths and Limitations

A particular strength of this study is the direct physical cervical testing of representative player cohorts, and the novel data presented.

A limitation is the assumed though unsubstantiated link between cervical strength and injury; though this is mitigated in this specific context through the known link between scrum collapse and cervical injury.

INTRODUCTION

Rugby is the world's most popular contact, or more appropriately collision, sport and carries an injury risk four times greater than semi-contact sports such as football/soccer.[1] The scrum is an iconic and fundamental part of the game, where two 'forward packs' compete for the ball to restart the game following a minor infringement. It is a test of strength and technique where the cervical spine of the opposing front rows are subjected to huge compressive and shear forces of a sufficient magnitude to result in tissue injury[2] and structural failure.

Around 8% of all injuries in professional rugby are thought to result from the scrum,[3, 4] and rates in amateur and youth rugby are thought to be similarly proportioned. Though this number is comparatively small, these injuries are likely to be of greater severity and involve the spine.[5] Despite a typical match consisting of comparatively few scrums (compared to other contact events, such as tackles), around 40% of all rugby derived acute spinal cord injuries occur in the scrum.[6, 7] Scrum engagement occurs as the head and shoulders of the competing front rows make forceful contact. This is thought to be a particular risk factor for injury, through high compressive and shear loads or hyperflexion of the cervical spine.[6-8] This risk has been somewhat mitigated in recent years by the introduction of 'controlled scrum engagement' where the distance between opposing front rows has been standardised in attempt to reduce acceleration and thus collision forces.[9, 10] Collapsing of the scrum has also been identified as a leading cause of scrum related injury.[6, 11] Premature micro trauma induced degeneration of the cervical spine in front row players[12] and mismatches in size between front row players[6, 13] have been suggested as potential factors for the over-representation of scrum-related injuries, though Brown et al.[7] note that coaching and technical factors have not been well explored in these analyses.

Body size and physical mismatch are considered (at least in part) to be associated to injury risk in schoolboy rugby.[14] Some national governing bodies have introduced a weight category banding for youth rugby to address this concern in children who mature skeletally at differing rates. However once players reach the age of 18 all participants are considered as adults and no such segregation takes place, indeed rugby is a sport that relies on differing physical attributes for the various playing positions. There are circumstances though where those yet to reach their 18th birthday may wish to play adult rugby, either through selection processes in the case of particularly gifted players, or through leaving school and joining a club playing in the adult leagues. Policy within Scottish Rugby (prior to the start of the 2013-2014 season) had been that only 'exceptional' 17 year-old players were eligible to play in the adult leagues however there was concern as to the suitability of this policy regarding the front row.

The scrum exposes players' cervical spines to potentially injurious forces that must be attenuated by controlled spinal motion through the cervical musculature, ligaments and inter-vertebral discs.[15] Appropriate strength of the cervical musculature is thus particularly important for front row players. We have previously demonstrated large variation in the neck strength of school-aged rugby players,[16] however we are not aware of any report of data specific to the front row forwards (either youth or adult).

The aim of this study was to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players to assess the ability of under18 players to compete with adults in the front row of the scrum. A secondary objective was to assess the relationship between isometric strength, and various other physical parameters previously shown to predict this.

METHODS

Study design and population

A cross-sectional cohort study was undertaken to investigate the isometric neck strength and fatigue endurance of front row rugby players. 30 senior school-aged players (under-18 age-grade) were assessed at a Scottish Rugby Union (SRU) training day, and 22 adult players in a separate assessment, again organised in conjunction with the SRU.

The youth players were drawn from 21 different clubs/schools from across Scotland and represented the 'elite' end of the senior school-aged front row players in Scotland. The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). This range was decided upon to reflect the spectrum of levels that the under-18 group may play. Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams. Both adult and school-age testing sessions took place at the same facility in Murrayfield stadium in the same environment using the same equipment and operators. Participation was voluntary and signed consent was obtained from all participants. Regional Ethics Committee approval was received for this study.

Cervical strength and endurance assessment

Isometric cervical muscle testing is well validated.[17-19] We assessed maximal voluntary isometric cervical muscle strength with the GS Gatherer and GS Analysis Suite (Gatherer Systems Ltd, Aylesbury); a custom-built device based on a 300Kg load cell and bespoke software system.

The test was performed employing a previously reported protocol[16, 20] where the head was placed in the neutral anatomic position and subjected to manual controlled incremental loading to positional failure (the point of head movement). Subject report of pain or neurological symptoms also stopped the test. Loading was applied and data was recorded at 20Hz. Peak isometric force generated by the musculature was defined as the maximal load recorded during the test procedure. An average of 3 tests is reported, with a60 second rest period enforced between assessments.

An assessment of cervical musculature fatigue endurance was made using the same test equipment. The player was required to exert an isometric extension load at 50% of their recorded mean peak extension force for as long as possible. The player sat in a neutral position with their arms by their side and head connected to the load cell. Players received visual graphical feedback as to the target load applied via a computer monitor. This allowed for maintenance of a consistent load until failure. A single assessment was made of fatigue.

Anthropometric parameters

Additional measures were made of; height (Leicester Height Measure; SECA, UK), weight (medical grade mechanical flat scales; SECA, UK), grip strength (JAMAR hydraulic hand dynamometer; Sammoms Preston, Illinois, USA) and cervical range of motion (Cervical Range of Motion Instrument, Performance Attainment Associates, Minnesota, USA). 3 readings were obtained for each parameter and their average was derived and reported. Demographic data and a self-report questionnaire to determine the individual's rugby playing history and details of neck specific training and injuries were completed by the participants prior to physical assessment.

Data analysis

Data were analysed using Minitab (Version 16). Data were checked for normality and are reported as means with standard deviation or 95% confidence intervals of the mean as a measure of dispersion. Independent samples t-tests were used to assess differences in continuous variables between groups unless otherwise stated. Significance was accepted as $p < 0.05$ incorporating the Benjami-Hochberg correction for the testing of multiple hypotheses, to reduce the possibility of making a type I error in the interpretation of results.[21, 22]

To assess the secondary research question as to predictive modelling of front row player neck strength all data was considered as a single cohort. Pearson correlation coefficients are reported for bivariate correlations. Stepwise regression modelling was performed to achieve the most predictive model for global neck strength (for which we use isometric extension) utilising the fewest variables. Predictive variables were selected with a significance of $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables was controlled. A potential limitation of this approach is that the homogenised under-18 group may cause a clustering effect in the data. Separate analysis of the adult data demonstrates the same relationships as reported for the entire cohort lending credibility to the results presented. Further, all players assessed are eligible to play in the adult leagues and can thus be considered representative of a single cohort in the context of our secondary research question; to assess the influence of various physical variables (previously suggested to reflect the variation in cervical strength in a school aged population) in the specific situation of the front row player.

RESULTS

As expected, large differences were observed between groups in terms of age and experience (years) playing as a front row forward. There was no difference in height or grip strength between the groups, though the adults were significantly heavier. Cervical range of motion was similar in measures of extension and rotation, though the elite under-18 group had a greater range of cervical flexion and side flexion (table 1).

Substantial differences were observed in isometric strength between groups in extension (figure 1, table 2) and side flexion (table 2); the under 18 group approximately 20% weaker than the adult group. A larger variation was seen in all parameters of adult neck strength data compared to the under 18 group. This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data, only 2 of the 30 elite under-18 front row players achieved the adult mean strength value (figure 1).

Only 3 of the under-18s achieved the adult mean isometric extension fatigue endurance (impulse, table 2), this difference between groups was significant at $p < 0.1$, possibly reflecting the large variation in adult scores. The adults performed better in the fatigue assessment, holding significantly higher average loads for the same length of time as the younger players (table 2). Surprisingly, only a quarter of all players reported performing routine neck exercises; split evenly between groups (table 1).

Predictive modelling;
Isometric neck strength was most associated with the experience of playing in the front row ($r=0.5$, $p<0.001$) (Figure 2), followed by weight ($r=0.4$, $p=0.004$) and player age ($r=0.4$, $p=0.005$). In contrast, grip strength correlated relatively poorly ($r=0.2$, $p=0.09$) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly ($r=0.30$, $p=0.08$). Player weight ($r=0.6$, $p=0.007$) was the factor most associated with fatigue, again grip strength correlated poorly ($r=0.1$, $p=0.6$).

Stepwise regression determined the best predictive model for isometric strength to include the number of years' experience playing in the front row and the players' weight (table 3). The greatest single contributing variable was the experience of playing in the front row, which explained around 22% of the variation in isometric extension. The same variables also created the best predictive model of fatigue endurance, again explaining around a third of the variation in neck strength (R^2=0.4).

DISCUSSION

This study demonstrates that even elite under-18 front row rugby players, who have participated in a conditioning and strengthening programme, are able to generate significantly less cervical muscle force than their adult equivalents. This is highly relevant in determining the suitability of such players to compete in the adult game, where significant forces are exerted through the cervical spine of the front row forwards during the scrum. These forces must be modulated by the cervical musculature, and the reduced isometric strength and fatigue endurance ratings found in the under-18 players puts them at a significant disadvantage, with potentially injurious consequences. A particular concern is that the under-18 players evaluated in this study contained a selection bias of high performance age-grade players. While this group represents the players most likely to be considered appropriate to play in the adult leagues, it is also likely that they are bigger and stronger than their age-grade counterparts, suggesting that the actual difference between the adult and under-18 values in the wider population may be much greater.

Little information is available as to the 'neck strength' of rugby players, either adult or school-aged. We previously assessed the cervical isometric strength of Scottish school children between the ages of 13 and 18 and found huge variation both within and between year groups.[16] We are not aware of any other comparable data for adult players or of any study specifically investigating the cervical isometric strength of the front row forwards. Using multivariate techniques, we previously reported that player age, weight and grip strength (as an objective measure of overall strength) was strongly predictive of isometric neck extension strength in the general school-aged rugby playing population; explaining around two thirds of the variance in cervical strength. Interestingly in this analysis, the measure of grip strength was not a strong predictor of cervical strength in this specific group of front-row players, where player weight and number of years of experience of playing in the front row were the most important factors. This finding may be a reflection of the general lack of neck specific training performed among rugby players. It is likely that for most people scrummaging is the main source of cervical strength training and this is supported by the finding that only a quarter of the players assessed reported performing regular exercises for the neck. We propose that the elite under-18 players had reached the same global strength as their adult counterparts through peripheral strength training; however in the absence of specific structured conditioning, they could not match the cervical strength the adults had gained as a result of years of competitive scrummaging.

This is to our knowledge the first report of a cervical musculature fatigue endurance assessment in front row rugby players of any age. In the absence of previous data, it was necessary to set a safe threshold at which to perform the test, thus the 50% sub-maximal value was selected to determine reference values for adult and under-18 front row players. While large differences were observed in fatigue endurance values achieved between adult and under-18 players, the large spread of the data in the adult cohort diluted the significance of this finding. Though all players achieved a similar time on fatigue assessment, the 50% sub-maximal load held by the under-18 group (20kg equivalent) was significantly less than the adult 50% load (25kg equivalent), as a result of their lower peak forces on the maximal isometric testing. Now that these benchmark data are available, we recommend that future fatigue endurance assessment of under-18 players should be performed using the mean adult 50% sub-maximal value (25Kg equivalent), which would represent around 60% of the average under-18 maximal isometric value found in this study. It is likely that greater differences would be apparent between adults and under-18 groups had we been able to employ this testing design, and further help discern those able to compete in the adult front row. Future work should also look at assessing 'scrum-specific' fatigue endurance; looking perhaps at repeated bouts of 80% sub-maximal testing over 10-15 seconds which could be argued to better reflect the demands of this activity. We suggest this as an area for future research.

Preatoni et al.[2] assessed the forces generated in the scrum by 34 forward packs at 6 different playing grades (from senior-school to international level) and found notable differences in the forces generated between schools and senior sides. Worryingly, these authors further reported that the combined compression and shear forces they recorded in the scrums were of a sufficient magnitude to induce chronic spine injury. Though further information is needed to understand the link between mechanical forces in the scrum and injury, the shear forces recorded are of particular concern as a risk factor for chronic degeneration of the spine through undesirable rotation and bending motions. The differences in strength characteristics between adult and under-18 players we describe here suggests that appropriate and specific training interventions (perhaps through scrum training) are critical in developing the ability modulate these forces at an individual level.

Perhaps of greater concern is the closed kinetic chain situation of the scrum; where the head is constrained from moving and loads are applied at both ends. This can lead to a buclking motion; a process particularly evident in front row forwards when the scrum collapses and the head strikes the ground. If any single front row player has comparatively weak cervical extensors, it is reasonable to suggest that this may enhance the risk of scrum collapse. We suggest that specific training may influence this, thus younger players and perhaps also those returning from cervical injury are potentially at a competitive disadvantage. For the safety of all six front row players, it is important to recognize, understand and mitigate the biomechanical issues that occur in a closed kinetic chain situation where the forces cannot be vectored away from the spine.

A limitation of this study is the speculative link between cervical strength and scrum collapse and thus injury risk. Although the focus of our investigation was to consider cervical strength parameters, various other factors such as the speed and direction of force application and orientation of the head/neck complex are likely to also have a bearing on the ability to modulate scrum forces. The neutral anatomic position was chosen for strength and fatigue testing from a safety point of view due to the lack of published data to determine alternative test design. The validity of this test position as the optimal assessment profile for rugby cervical testing is unknown. Future work should focus on the influence of head position as to strength and fatigue values in this context. It must also be recognised that recent changes to the laws of the game surrounding scrum engagement, depowering the contact forces at the onset of the scrum and promoting a sustained pushing contest may influence the playing requirements of the cervical spine of the front rows. It may be that endurance parameters are now more critical than absolute strength characteristics, though further work is required to elaborate on any influence to beneficial physical characteristics as a result of this technical change.

In the elite under-18 group assessed, only 2 of 30 players recorded the mean cervical isometric strength of the adult cohort. Although a few individuals may possess the physical characteristics (and technical skill) to compete with adult players, our results suggest that policy should prevent players under the age of 18 playing in the front row of an adult match, unless specific criteria is met. In contrast to the general schoolboy population, predictive modelling of cervical strength using alternative physical characteristics was poor. As such, specific testing would need to be employed to identify those few individuals able to match their adult counterparts in terms of cervical strength. The concept of a passport to play in the front row is well established in some countries as a means of ensuring players are appropriately equipped to cope with the rigours of scrummaging. Objective measures of the individuals' cervical strength profile should be an integral part of any selection process for players wishing to play in the front row.

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AUTHOR CONTRIBUTIONS

All authors listed were involved in the study design and data acquisition. DH performed the analysis and drafted the manuscript. All authors revised and approved the submission.

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CONFLICT OF INTEREST

DG has shares in Gatherer Systems who manufacture and supplied the testing equipment used in this study. The other authors declare no conflict of interest.

DATA SHARING STATEMENT

The data are held in a secure database at the University of Edinburgh. Any party wishing to access unpublished data should discuss with the corresponding author in the first instance.

REFERENCES

[1]. Palmer-Green DS, Stokes KA, Fuller CW, et al. Match injuries in English youth academy and schools rugby union: an epidemiological study. *Am J Sports Med*. 2013;41:749-55.

[2]. Preatoni E, Stokes KA, England ME, et al. The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scand J Med Sci Sports* 2013;23:178-184

[3]. Brooks JHM, Fuller CW, Kemp SPT, et al. Epidemiology of injuries in English Professional rugby union: part 1 match injuries. *Br J Sports Med* 2005:39:757-766

[4]. Brooks JHM, Fuller CW, Kemp SPT,et al. Epidemiology of injuries in English Professional rugby union: part 2 training injuries. *Br J Sports Med* 2005:39:767-775

[5]. MacLean JG, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great Britain and Ireland. *Br J Sports Med* 2012;46:591-4.

[6]. Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and spinal cord. *Sports Med* 2002;32:633-53

[7]. Brown JC, lambert MI, Verhagen E, et al. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohrot study. BMJ open 2013;3:e002475

[8]. Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players *Br J Sports Med* 2011;45:765–775.

[9]. Gianotti S, Hume PA, Hopkins WG, et al. Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *Br J Sports Med* 2013;42:427-430

[10]. Fuller CW, Brooks JH, Kemp SP. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med*. 2007;17:10-6

[11] Roberts SP, Trewartha G, England M, et al. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* [e-pub ahead of print]

[12]. Scher AT. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clin Sports Med*. 1998;17:195-206

[13]. Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med*. 2012;46:692-3

[14]. Nutton RW, Hamilton DF, Hutchison JD, et al. Variation in physical development in schoolboy rugby players: can maturity testing reduce mismatch? *BMJ Open*. 2012;2:e001149

[15]. Torg J, Ramsey-Emrhein J. Suggested management guidelines for participation in collision activities with congenital, developmental, or post injury lesions involving the cervical spine. *Med Sci Sports Exerc*, 1997;29(7):256–272.

[16]. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A CROSS-SECTIONAL COHORT STUDY OF SCOTTISH SCHOOLCHILDREN. *Bone Joint Res* 2012;1:152–7.

[17]. Garge´s GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc* 2002;33:464-70.

[18]. Jordan A, Mehlsen J, Bu¨low PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine* 1999;24:1343-8.

[19]. Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil* 2002;16:851-8.

[20]. Peek K, Gatherer D. The rehabilitation of a professional rugby union player following a C7/T1 posterior microdiscectomy. *Phys Ther Sport* 2005;**6**:195–200.

[21]. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Statist. Soc.* B 1995;**57**, 289–300.

[22]. Storey JD, "The positive false discovery rate: A Bayesian interpretation and the q-value" *Annals of Statistics* 2003;31: 2013–2035

TABLES

Table 1- Anthropometric data

	Under 18	Adult	Significance
Age (years)	16.7 (16-17)	27.2 (19-50)	<0.001‡
Experience of the front row (years)	5.0 (1-12)	14.3 (2-26)	<0.001‡
Regular neck strengthening (yes/no)	7/23	5/21	0.959*
Height (cm)	178.7 (5.54)	178.7 (5.91)	0.960
Weight (kg)	96.0 (13.69)	107.8 (13.67)	0.004‡
Grip strength (kg)	47.8 (5.31)	49.56 (7.56)	0.360
Cervical Range of Motion (degrees)			
Extension	65.33 (8.70)	65.62 (6.62)	0.895
Flexion	58.50 (8.32)	44.10 (8.93)	<0001‡
Side flexion (left)	49.17 (5.88)	44.33 (6.51)	0.010‡
Side flexion (right)	45.60 (8.93)	41.33 (6.18)	0.049
Rotation (left)	66.50 (7.67)	65.90 (6.80)	0.772
Rotation (right)	67.83 (8.06)	64.76 (6.83)	0.149

Age and experience reported as mean (range), all other variables as mean (SD); ‡ Remains significant at the 0.05 level correcting for multiple testing; *Chi Square

Table 2 - Cervical strength assessment

	Under 18	Adult	Significance
Isometric Strength (kg)			
Extension	41.70 (39.36, 44.18)	53.70 (48.42, 58.99)	<0.001‡
Flexion	22.59 (20.45, 24.72)	25.40 (22.94, 27.86)	0.098
Side flexion (left)	32.24 (30.04, 34.45)	40.53 (36.36, 44.71)	0.002‡
Side flexion (right)	31.83 (29.66, 24.01)	42.48 (39.24, 45.73)	<0.001‡
Fatigue			
Total (kg.sec)	1305 (1181, 1429)	1551 (1332, 1770)	0.058
Time achieved (sec)	67.10 (60.44, 83.17)	71.81 (62.96, 71.28)	0.390
Average load (kg)	18.25 (16.77, 19.73)	23.54 (21.35, 25.73)	<0.001‡

All data reported as mean (95% CI). ‡ Remains significant at the 0.05 level correcting for multiple testing

Table 3 – Multivariate predictive modelling of isometric neck extension (R^2=0.31)

Predictor	Co-efficient	P value

Front row experience	0.63	0.035
Weight	0.22	0.003

Front row experience is the primary predictor variable explaining 22% of the total variation, adding weight as a predictor determines the best fit model (dispoayed above). Other variations offer less than 1% additional enhanced explanatory power with the limitation of comprising more predictor variables and were thus discounted.

FIGURE LEGEND

Figure 1 - Differences in cervical strength by group

Figure 2 – Strong relationship between cervical strength and playing experience

Figure 3 – Weak relationship between grip strength and cervical strength

Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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Rugby is the world's most popular contact, or more appropriately collision, sport and carries an injury risk four times greater than semi-contact sports such as football/soccer.[1] The scrum is an iconic and fundamental part of the game, where two 'forward packs' compete for the ball to restart the game following a minor infringement. It is a test of strength and technique where the cervical spine of the opposing front rows are subjected to huge compressive and shear forces of a sufficient magnitude to result in tissue injury[2] and structural failure.

Around 8% of all injuries in professional rugby are thought to result from the scrum,[3, 4] and rates in amateur and youth rugby are thought to be similarly proportioned. Though this number is comparatively small, these injuries are likely to be of greater severity and involve the spine.[5] Despite a typical match consisting of comparatively few scrums (compared to other contact events, such as tackles), around 40% of all rugby derived acute spinal cord injuries occur in the scrum.[6, 7] Scrum engagement occurs as the head and shoulders of the competing front rows make forceful contact. This is thought to be a particular risk factor for injury, through high compressive and shear loads or hyperflexion of the cervical spine.[6-8] This risk has been somewhat mitigated in recent years by the introduction of 'controlled scrum engagement' where the distance between opposing front rows has been standardised in attempt to reduce acceleration and thus collision forces.[9, 10] Collapsing of the scrum has also been identified as a leading cause of scrum related injury.[6, 11] Premature micro trauma induced degeneration of the cervical spine in front row players[12~~1~~] and mismatches in size between front row players[6, 13~~2~~] have been suggested as potential factors for the over-representation of scrum-related injuries, though Brown et al.[7] note that coaching and technical factors have not been well explored in these analyses.

Body size and physical mismatch are considered (at least in part) to be associated to injury risk in schoolboy rugby.[14~~3~~] Some national governing bodies have introduced a weight category banding for youth rugby to address this concern in children who mature skeletally at differing rates. However once players reach the age of 18 all participants are considered as adults and no such segregation takes place, indeed rugby is a sport that relies on differing physical attributes for the various playing positions. There are circumstances though where those yet to reach their 18th birthday may wish to play adult rugby, either through selection processes in the case of particularly gifted players, or through leaving school and joining a club playing in the adult leagues. Policy within Scottish Rugby (prior to the start of the 2013-2014 season) had been that only 'exceptional' 17 year-old players were eligible to play in the adult leagues however there was concern as to the suitability of this policy regarding the front row.

The scrum exposes player~~'~~s' cervical spines to potentially injurious forces that must be attenuated by controlled spinal motion through the cervical musculature, ligaments and inter-vertebral discs.[15~~4~~] Appropriate strength of the cervical musculature is thus particularly important for front row players. We have previously demonstrated large variation in the neck strength of school-aged rugby players,[16~~5~~] however we are not aware of any report of data specific to the front row forwards (either youth or adult).

The aim of this study was to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players to assess the ability of under18 players to compete with adults in the front row of the scrum. A secondary objective was to assess the relationship between isometric strength, and various other physical parameters previously shown to predict this.

METHODS

Study design and population

A cross-sectional cohort study was undertaken to investigate the isometric neck strength and fatigue endurance of front row rugby players. 30 senior school-aged players (under-18 age-grade) were assessed at a Scottish Rugby Union (SRU) training day, and 22 adult players in a separate assessment, again organised in conjunction with the SRU.

The youth players were drawn from 21 different clubs/schools from across Scotland and represented the ‘elite’ end of the senior school-aged front row players in Scotland. The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). This range was decided upon to reflect the spectrum of levels that the under-18 group may play. Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams. Both adult and school-age testing sessions took place at the same facility in Murrayfield stadium in the same environment using the same equipment and operators. Participation was voluntary and signed consent was obtained from all participants. Regional Ethics Committee approval was received for this study.

Cervical strength and endurance assessment

Isometric cervical muscle testing is well validated.[17~~6~~-19~~8~~] We assessed maximal voluntary isometric cervical muscle strength with the GS Gatherer and GS Analysis Suite (Gatherer Systems Ltd, Aylesbury); a custom-built device based on a 300Kg load cell and bespoke software system.

The test was performed employing a previously reported protocol[16~~5~~, 20~~19~~] where the head was placed in the neutral anatomic position and subjected to manual controlled incremental loading to positional failure (the point of head movement). Subject report of pain or neurological symptoms also stopped the test. Loading was applied and data was recorded at 20Hz. Peak isometric force generated by the musculature was defined as the maximal load recorded during the test procedure. An average of 3 tests is reported, with a~~. ~~60 second rest period enforced between assessments.

An assessment of cervical musculature fatigue endurance was made using the same test equipment. The player was required to exert an isometric extension load at 50% of their recorded mean peak extension force for as long as possible. The player sat in a neutral position with their arms by their side and head connected to the load cell. Players received visual graphical feedback as to the target load applied via a computer monitor. This allowed for maintenance of a consistent load until failure. A single assessment was made of fatigue.

Anthropometric parameters

Additional measures were made of; height (Leicester Height Measure; SECA, UK), weight (medical grade mechanical flat scales; SECA, UK), grip strength (JAMAR hydraulic hand dynamometer; Sammoms Preston, Illinois, USA) and cervical range of motion (Cervical Range of Motion Instrument, Performance Attainment Associates, Minnesota, USA). 3 readings were obtained for each parameter and their average was derived and reported. Demographic data and a self-report questionnaire to determine the individual’s rugby playing history and details of neck specific training and injuries were completed by the participants prior to physical assessment.

Data analysis

Data were analysed using Minitab (Version 16). Data were checked for normality and are reported as means with standard deviation or 95% confidence intervals of the mean as a measure of dispersion. Independent samples t-tests were used to assess differences in continuous variables between groups unless otherwise stated. Significance was accepted as $p < 0.05$ incorporating the Benjami-Hochberg correction for the testing of multiple hypotheses, to reduce the possibility of making a type II error in the interpretation of results.[210, 221]

To assess the secondary research question as to predictive modelling of front row player neck strength all data was considered as a single cohort. Pearson correlation coefficients are reported for bivariate correlations. Pearson correlation coefficients are reported for bivariate correlations. Multivariate sStepwise regression modelling was performed to achieve the most predictive model for global neck strength (for which we use isometric extension) utilising the fewest variables. Predictive variables were selected with a significance of $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables was controlled. A potential limitation of this approach is that the homogenised under-18 group may cause a clustering effect in the data. Separate analysis of the adult data demonstrates the same relationships as reported for the entire cohort lending credibility to the results presented. Further, all players assessed are eligible to play in the adult leagues and can thus be considered representative of a single cohort in the context of our secondary research question; to assess the influence of various physical variables (previously suggested to reflect the variation in cervical strength in a school aged population) in the specific situation of the front row player.

RESULTS

As expected, large differences were observed between groups in terms of age and experience (years) playing as a front row forward. There was no difference in height or grip strength between the groups, though the adults were significantly heavier. Cervical range of motion was similar in measures of extension and rotation, though the elite under-18 group had a greater range of cervical flexion and rotation side flexion (table 1).

Substantial differences were observed in isometric strength between groups in extension (figure 1, table 2) and side flexion (table 2); the under 18 group approximately 20% weaker than the adult group. A larger variation was seen in all parameters of adult neck strength data compared to the under 18 group. This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data, only 2 of the 30 elite under-18 front row players achieved the adult mean strength value (figure 12).

Only 3 of the under-18s achieved the adult mean isometric extension fatigue endurance (total work,impulse, figure 1table 2), this difference between groups was significant at $p < 0.1$, possibly reflecting the large variation in adult scores. The adults performed better in the fatigue assessment, holding significantly higher average loads for the same length of time as the younger players (table 2). Surprisingly, only a quarter of all players reported performing routine neck exercises; split evenly between groups (table 1).

Predictive modelling;

Isometric neck strength was most associated with the experience of playing in the front row ($r=0.5$, $p<0.001$) (Figure 2), followed by weight ($r=0.4$, $p=0.004$) and player age ($r=0.4$, $p=0.005$). In contrast, grip strength correlated relatively poorly ($r=0.2$, $p=0.09$) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly ($r=0.30$, $p=0.08$). Player weight ($r=0.6$, $p=0.007$) was the factor most associated with fatigue, again grip strength correlated poorly ($r=0.1$, $p=0.6$).

Multivariate Stepwise regression found determined the best predictive model for isometric strength to include the number of years' experience playing in the front row and the players' weight (table 3). The greatest single contributing variable was the experience of playing in the front row, which explained around 22% of the variation in isometric extension. The same variables also created the best predictive model of fatigue endurance, again explaining around a third of the variation in neck strength (R^2=0.4).

DISCUSSION

This study demonstrates that even elite under-18 front row rugby players, who have participated in a conditioning and strengthening programme, are able to generate significantly less cervical muscle force than their adult equivalents. This is highly relevant in determining the suitability of such players to compete in the adult game, where significant forces are exerted through the cervical spine of the front row forwards during the scrum. These forces must be modulated by the cervical musculature, and the reduced isometric strength and fatigue endurance ratings found in the under-18 players puts them at a significant disadvantage, with potentially injurious consequences. A particular concern is that the under-18 players evaluated in this study contained a selection bias of high performance age-grade players. While this group represents the players most likely to be considered appropriate to play in the adult leagues, it is also likely that they are bigger and stronger than their age-grade counterparts, suggesting that the actual difference between the adult and under-18 values in the wider population may be much greater.

Little information is available as to the 'neck strength' of rugby players, either adult or school-aged. We previously assessed the cervical isometric strength of Scottish school children between the ages of 13 and 18 and found huge variation both within and between year groups.[16~~5~~] We are not aware of any other comparable data for adult players or of any study specifically investigating the cervical isometric strength of the front row forwards. Using multivariate techniques, we previously reported that player age, weight and grip strength (as an objective measure of overall strength) was strongly predictive of isometric neck extension strength in the general school-aged rugby playing population; explaining around two thirds of the variance in cervical strength. Interestingly in this analysis, the measure of grip strength was not a strong predictor of cervical strength in this specific group of front-row players, where player weight and number of years of experience of playing in the front row were the most important factors. This finding may be a reflection of the general lack of neck specific training performed among rugby players. It is likely that for most people scrummaging is the main source of cervical strength training and this is supported by the finding that only a quarter of the players assessed reported performing regular exercises for the neck. We propose that the elite under-18 players had reached the same global strength as their adult counterparts through peripheral strength training; however in the absence of specific structured conditioning, they could not match the cervical strength the adults had gained as a result of years of competitive scrummaging.

This is to our knowledge the first report of a cervical musculature fatigue endurance assessment in front row rugby players of any age. In the absence of previous data, it was necessary to set a safe threshold at which to perform the test, thus the 50% sub-maximal value was selected to determine reference values for adult and under-18 front row players. While large differences were observed in fatigue endurance values achieved between adult and under-18 players, the large spread of the data in the adult cohort diluted the significance of this finding. Though all players achieved a similar time on fatigue assessment, the 50% sub-maximal load held by the under-18 group (20kg equivalent) was significantly less than the adult 50% load (25kg equivalent), as a result of their lower peak forces on the maximal isometric testing. Now that these benchmark data are available, we recommend that future fatigue endurance assessment of under-18 players should be performed using the mean adult 50% sub-maximal value (25Kg equivalent), which would represent around 60% of the average under-18 maximal isometric value found in this study. It is likely that greater differences would be apparent between adults and under-18 groups had we been able to employ this testing design, and further help discern those able to compete in the adult front row. Future work should also look at assessing 'scrum-specific' fatigue endurance; looking perhaps at repeated bouts of 80% sub-maximal testing over 10-15 seconds which could be argued to better reflects the demands of this activity. We suggest this as an area for future research.

Preatoni et al.[2] assessed the forces generated in the scrum by 34 forward packs at 6 different playing grades (from senior-school to international level) and found notable differences in the forces generated between schools and senior sides. Worryingly, these authors further reported that the combined compression and shear forces they recorded in the scrums were of a sufficient magnitude to induce chronic spine injury. Though further information is needed to understand the link between mechanical forces in the scrum and injury, the shear forces recorded are of particular concern as a risk factor for chronic degeneration of the spine through undesirable rotation and bending motions. The differences in strength characteristics between adult and under-18 players we describe here suggests that appropriate and specific training interventions (perhaps through scrum training) are critical in developing the ability modulate these forces at an individual level.

Perhaps of greater concern is the closed kinetic chain situation of the scrum; where the head is constrained from moving and loads are applied at both ends. This can lead to a buclking motion; a process particularly evident in front row forwards when the scrum collapses and the head strikes the ground. If any single front row player has comparatively weak cervical extensors, it is reasonable to suggest that this may enhance the risk of scrum collapse. We suggest that specific training may influence this, thus younger players and perhaps also those returning from cervical injury are potentially at a competitive disadvantage. For the safety of all six front row players, it is important to recognize, understand and mitigate the biomechanical issues that occur in a closed kinetic chain situation where the forces cannot be vectored away from the spine.

A limitation of this study is the speculative link between cervical strength and scrum collapse and thus injury risk. Although the focus of our investigation was to consider cervical strength parameters, various other factors such as the speed and direction of force application and orientation of the head/neck complex are likely to also have a bearing on the ability to modulate scrum forces. The neutral anatomic position was chosen for strength and fatigue testing from a safety point of view due to the lack of published data to determine alternative test design. The validity of this test position as the optimal assessment profile for rugby cervical testing is unknown. Future work should focus on the influence of head position as to strength and fatigue values in this context. It must also be recognised that recent changes to the laws of the game surrounding scrum engagement, depowering the contact forces at the onset of the scrum and promoting a sustained pushing contest may influence the playing requirements of the cervical spine of the front rows. It may be that endurance parameters are now more critical than absolute strength characteristics, though further work is required to elaborate on any influence to beneficial physical characteristics as a result of this technical change.

In the elite under-18 group assessed, only 2 of 30 players recorded the mean cervical isometric strength of the adult cohort. Although a few individuals may possess the physical characteristics (and technical skill) to compete with adult players, our results suggest that policy should prevent players under the age of 18 playing in the front row of an adult match, unless specific criteria is met. In contrast to the general schoolboy population, predictive modelling of cervical strength using alternative physical characteristics was poor. As such, specific testing would need to be employed to identify those few individuals able to match their adult counterparts in terms of cervical strength. The concept of a passport to play in the front row is well established in some countries as a means of ensuring players are appropriately equipped to cope with the rigours of scrummaging. Objective measures of the individuals' cervical strength profile should be an integral part of any selection process for players wishing to play in the front row.

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AUTHOR CONTRIBUTIONS

All authors listed were involved in the study design and data acquisition. DH performed the analysis and drafted the manuscript. All authors revised and approved the submission.

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CONFLICT OF INTEREST

DG has shares in Gatherer Systems who manufacture and supplied the testing equipment used in this study. The other authors declare no conflict of interest.

DATA SHARING STATEMENT

The data are held in a secure database at the University of Edinburgh. Any party wishing to access unpublished data should discuss with the corresponding author in the first instance.

REFERENCES

[1]. Palmer-Green DS, Stokes KA, Fuller CW, et al. Match injuries in English youth academy and schools rugby union: an epidemiological study. *Am J Sports Med*. 2013;41:749-55.

[2]. Preatoni E, Stokes KA, England ME, et al. The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scand J Med Sci Sports* 2013;23:178-184

[3]. Brooks JHM, Fuller CW, Kemp SPT, et al. Epidemiology of injuries in English Professional rugby union: part 1 match injuries. *Br J Sports Med* 2005:39:757-766

[4]. Brooks JHM, Fuller CW, Kemp SPT,et al. Epidemiology of injuries in English Professional rugby union: part 2 training injuries. *Br J Sports Med* 2005:39:767-775

[5]. MacLean JG, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great Britain and Ireland. *Br J Sports Med* 2012;46:591-4.

[6]. Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and spinal cord. *Sports Med* 2002;32:633-53

[7]. Brown JC, lambert MI, Verhagen E, et al. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohrot study. BMJ open 2013;3:e002475

[8]. Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players *Br J Sports Med* 2011;45:765–775.

[9]. Gianotti S, Hume PA, Hopkins WG, et al. Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *Br J Sports Med* 2013;42:427-430

[10]. Fuller CW, Brooks JH, Kemp SP. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med*. 2007;17:10-6

[11] Roberts SP, Trewartha G, England M, et al. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* [e-pub ahead of print]

[12~~1~~]. Scher AT. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clin Sports Med*. 1998;17:195-206

[13~~2~~]. Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med*. 2012;46:692-3

[14~~3~~]. Nutton RW, Hamilton DF, Hutchison JD, et al. Variation in physical development in schoolboy rugby players: can maturity testing reduce mismatch? *BMJ Open*. 2012;2:e001149

[15~~4~~]. Torg J, Ramsey-Emrhein J. Suggested management guidelines for participation in collision activities with congenital, developmental, or post injury lesions involving the cervical spine. *Med Sci Sports Exerc*, 1997;29(7):256–272.

[16~~5~~]. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A CROSS-SECTIONAL COHORT STUDY OF SCOTTISH SCHOOLCHILDREN. *Bone Joint Res* 2012;1:152–7.

[17~~6~~]. Garge´s GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc* 2002;33:464-70.

[18~~7~~]. Jordan A, Mehlsen J, Bu¨low PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine* 1999;24:1343-8.

[19~~8~~]. Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil* 2002;16:851-8.

[20~~19~~]. Peek K, Gatherer D. The rehabilitation of a professional rugby union player following a C7/T1 posterior microdiscectomy. *Phys Ther Sport* 2005;**6**:195–200.

[21~~0~~]. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Statist. Soc.* B 1995;**57**, 289–300.

[22~~1~~]. Storey JD, "The positive false discovery rate: A Bayesian interpretation and the q-value" *Annals of Statistics* 2003;31: 2013–2035

TABLES

Table 1- Anthropometric data

	Under 18	Adult	Significance
Age (years)	16.7 (16-17)	27.2 (19-50)	<0.001‡
Experience of the front row (years)	5.0 (1-12)	14.3 (2-26)	<0.001‡
Regular neck strengthening (yes/no)	7/23	5/21	0.959*
Height (cm)	178.7 (5.54)	178.7 (5.91)	0.960
Weight (kg)	96.0 (13.69)	107.8 (13.67)	0.004‡
Grip strength (kg)	47.8 (5.31)	49.56 (7.56)	0.360
Cervical Range of Motion (degrees)			
Extension	65.33 (8.70)	65.62 (6.62)	0.895
Flexion	58.50 (8.32)	44.10 (8.93)	<0001‡
Side flexion (left)	49.17 (5.88)	44.33 (6.51)	0.010‡
Side flexion (right)	45.60 (8.93)	41.33 (6.18)	0.049
Rotation (left)	66.50 (7.67)	65.90 (6.80)	0.772
Rotation (right)	67.83 (8.06)	64.76 (6.83)	0.149

Age and experience reported as mean (range), all other variables as mean (SD); ‡ Remains significant at the 0.05 level correcting for multiple testing; *Chi Square

Table 2 - Cervical strength assessment

	Under 18	Adult	Significance
Isometric Strength (kg)			
Extension	41.70 (39.36, 44.18~~6.74~~)	53.70 (48.42, 58.99~~12.36~~)	<0.001‡
Flexion	22.59 (20.45, 24.72~~5.96~~)	25.40 (22.94, 27.86~~5.76~~)	0.098
Side flexion (left)	32.24 (30.04, 34.45~~6.16~~)	40.53 (36.36, 44.71~~9.76~~)	0.002‡
Side flexion (right)	31.83 (29.66, 24.01~~6.08~~)	42.48 (39.24, 45.73~~7.59~~)	<0.001‡
Fatigue			
Total (kg.~~/~~sec)	1305 (1181, 1429~~236.8~~)	1551 (1332, 1770~~512~~)	0.058
Time achieved (sec)	67.10 (60.44, 83.17~~21.67~~)	71.81 (62.96, 71.28~~9.73~~)	0.390
Average load (kg)	18.25 (16.77, 19.73~~2.82~~)	23.54 (21.35, 25.73~~5.13~~)	<0.001‡

All data reported as mean (95% CI~~SD~~). ‡ Remains significant at the 0.05 level correcting for multiple testing

Table 3 – Multivariate predictive modelling of isometric neck extension (R^2=0.31)

Predictor	Co-efficient	P value

Front row experience	0.63	0.035
Weight	0.22	0.003

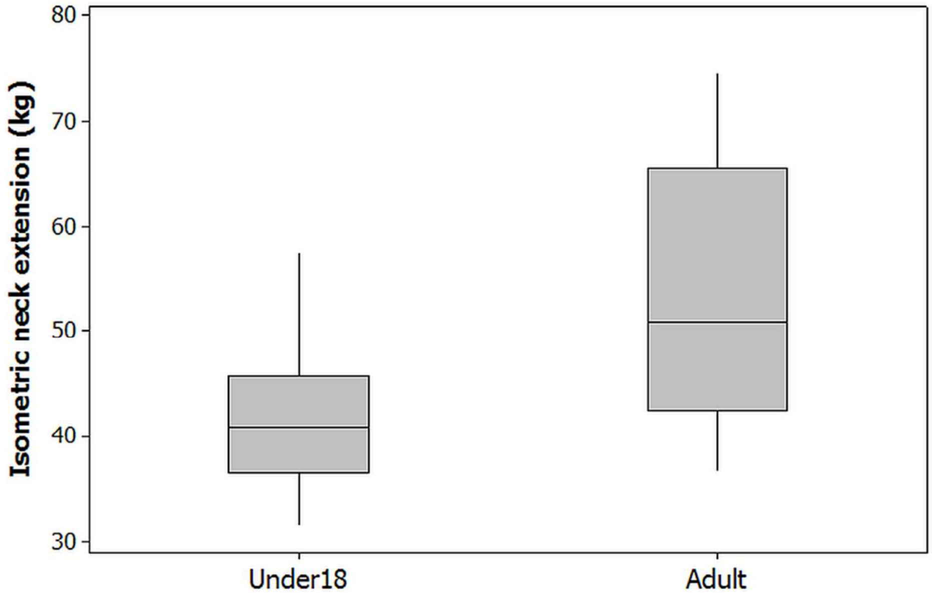
Front row experience is the primary predictor variable explaining 22% of the total variation, adding weight as a predictor determines the best fit model (dispoayed above). Other variations offer less than 1% additional enhanced explanatory power with the limitation of comprising more predictor variables and were thus discounted.

FIGURE LEGEND

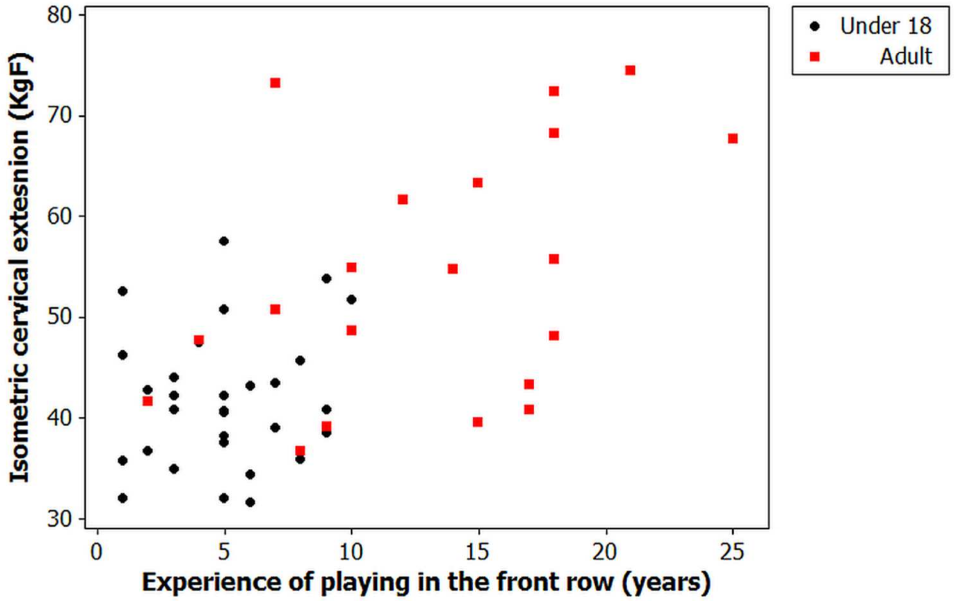
Figure 1 - Differences in cervical strength by group

Figure 2 – Strong relationship between cervical strength and playing experience

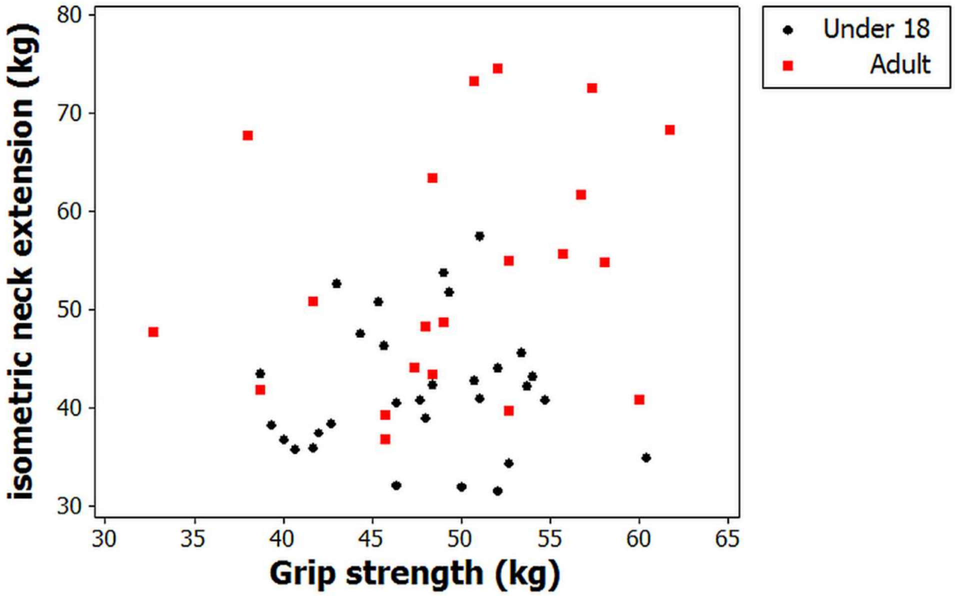
Figure 3 – Weak relationship between grip strength and cervical strength



Differences in cervical isometric extension
90x59mm (300 x 300 DPI)



Strong relationship between cervical strength and playing experience
90x60mm (300 x 300 DPI)



Weak relationship between grip strength and cervical strength
90x59mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3,4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	4
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	4
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	4
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	4
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	4
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	5
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	6, 7, 8
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	6, 7, 8
Generalisability	21	Discuss the generalisability (external validity) of the study results	8, 9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	9

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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KEY WORDS

Rugby; neck, injury, strength

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ABSTRACT

Objectives: To compare the cervical isometric strength, fatigue endurance and range of motion of adult and under-18 age grade front row rugby players to inform the development of a safe age group policy with particular reference to scrummaging.

Design: Cross-sectional cohort study.

Setting: 'Field testing' at Murrayfield stadium.

Participants: 30 high performance under-18 players and 21 adult front row rugby players

Outcome measures: Isometric neck strength, height, weight and grip strength.

Results: Youth players demonstrated the same height and grip strength as the adult players; however the adults were significantly heavier and demonstrated substantially greater isometric strength ($p < 0.001$). Only 2 of the 'elite' younger players could match the adult mean cervical isometric strength value. In contrast to school age players in general, grip strength was poorly associated with neck strength ($r=0.2$) in front row players; instead player weight ($r=0.4$) and the number of years' experience of playing in the front row ($r=0.5$) were the only relevant factor in multivariate modelling of cervical strength ($R^2=0.3$).

Conclusions: Extreme forces are generated between opposing front rows in the scrum and avoidance of mismatch is important if the risk of injury is to be minimised. Although elite youth front row rugby players demonstrate the same peripheral strength as their adult counterparts on grip testing, the adults demonstrate significantly greater cervical strength. If older youths and adults are to play together, such findings have to be noted in the development of age group policies with particular reference to the scrum.

ARTICLE SUMMARY

Key Findings

Front row rugby players under the age of 18 cannot resist the same cervical loads as adult front row players.

In contrast to general findings on youth players, predictive modelling of cervical strength by proxy measures in this specific group is poor and direct testing is required.

This is directly relevant to age related playing policy for under-18s competing in the front row in the adult game as appropriate neck strength is likely to be important in preventing scrum collapse and the associated injuries.

Age related playing policy should reflect both generic and position specific physical ability

Strengths and Limitations

A particular strength of this study is the direct physical cervical testing of representative player cohorts, and the novel data presented.

A limitation is the assumed though unsubstantiated link between cervical strength and injury; though this is mitigated in this specific context through the known link between scrum collapse and cervical injury.

INTRODUCTION

Rugby Union (henceforth Rugby) is the world's most popular contact, or more appropriately collision sport, and carries an injury risk four times greater than semi-contact sports such as football/soccer.[1] The scrum is an iconic and fundamental part of the game, where two 'forward packs' compete for the ball to restart the game following a minor infringement. It is a test of strength and technique where the cervical spine of the opposing front rows are subjected to huge compressive and shear forces of a sufficient magnitude to result in tissue injury and structural failure[2].

Around 8% of all injuries in professional rugby are thought to result from the scrum[3, 4]. Injury events s in amateur and youth rugby are thought to be similarly proportioned [5],Though 8% represents a comparatively small proportion of the injury burden, these injuries are likely to be of greater severity and involve the spine.[6] Despite a typical match consisting of comparatively few scrums (compared to other contact events, such as tackles), around 40% of all rugby derived acute spinal cord injuries occur in the scrum.[7, 8] Scrum engagement occurs as the head and shoulders of the competing front rows make forceful contact. The force generated in the scrum engagement is thought to be a particular risk factor for injury, through high compressive and shear loads or hyperflexion of the cervical spine.[7-9] This risk has been somewhat mitigated in recent years by the introduction of 'controlled scrum engagement' where the distance between opposing front rows has been standardised in an attempt to reduce acceleration and thus collision forces.[10, 11] Scrum collapse has also been identified as a leading cause of scrum related injury.[7, 12] Premature micro trauma induced degeneration of the cervical spine in front row players[13] and mismatches in size between front row players[7, 14] have been suggested as potential factors for the over-representation of scrum-related injuries, though Brown et al.[8] note that coaching and technical factors have not been well explored in these analyses.

Body size and physical mismatch are considered (at least in part) to be associated with injury risk in schoolboy rugby.[15] Some national governing bodies have introduced a weight category banding for youth rugby to address this concern in children who mature skeletally at differing rates. However, once players reach the age of 18 all participants are considered as adults and no such segregation takes place, and the banding rule no longer applies. Indeed rugby is a sport that relies on differing physical attributes for the various playing positions. There are circumstances though where those yet to reach their 18th birthday may wish to play adult rugby, either through selection processes in the case of particularly gifted players, or through leaving school and joining a club playing in the adult leagues. Policy within Scottish Rugby (prior to the start of the 2013-2014 season) had been that only 'exceptional' 17 year-old players were eligible to play in the adult leagues, however, there was concern as to the suitability of this policy regarding the front row.

Though adequate cervical strength is relevant to all rugby players, the scrum exposes players' cervical spines to potentially injurious forces that must be attenuated by controlled spinal motion through the cervical musculature, ligaments and inter-vertebral discs.[16] Appropriate strength of the cervical musculature is thus particularly important for front row players. The risk of scrum collapse (and by extension associated injuries) is increased if any of the 6 front row players cannot maintain the muscular force required to complete the scrum. The overall compressive and shear forces generated in the scrum are only now being defined. These have been demonstrated to vary by playing level, with youth teams generating significantly lower forces than adult sides[2]. However the relationship between these overall scrum forces and the mechanisms by which the individual front row players modulate them has not been explored. We have previously demonstrated large variation in the neck strength of school-aged rugby players,[17] however we are not aware of any report of data on maximal strength or fatigue endurance specific to the front row forwards (either youth or adult).Characterisation of the strength profiles of the cervical spine of this specific group is thus warranted.

The aim of this study was to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players to assess the ability of under18 players to compete with adults in the front row of the scrum. A secondary objective was to assess the relationship between isometric strength, and various physical parameters (such as age, weight and grip strength) previously shown to predict this.

METHODS

Study design and sample

A cross-sectional cohort study was undertaken to investigate the isometric neck strength and fatigue endurance of front row rugby players. Thirty senior school-aged players (under-18 age-grade) were assessed at Murrayfield stadium in tandem with aScottish Rugby Union (SRU) arranged front row coaching session, and 22 adult players in a separate assessment, again at Murrayfield stadium, organised in conjunction with the SRU.

The youth players were drawn from 21 different clubs/schools from across Scotland and represented the 'elite' end of the senior school-aged front row players in Scotland. The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). This range was decided upon to reflect the spectrum of levels that the under-18 group may play. Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams. Both adult and school-age testing sessions took place at the same facility in the same environment using the same equipment and operators. Participation was voluntary and signed consent was obtained from all participants. Regional Ethics Committee approval was received for this study.

Cervical strength and endurance assessment

Isometric cervical muscle testing is well validated.[18-20] We assessed maximal voluntary isometric cervical muscle strength with the GS Gatherer and GS Analysis Suite (Gatherer Systems Ltd, Aylesbury); a custom-built device based on a 300Kg load cell and bespoke software system.

The test was performed employing a previously reported protocol[17, 21] where the head was placed in the neutral anatomic position and subjected to manual controlled incremental loading to positional failure (the point of head movement). Subject report of pain or neurological symptoms also stopped the test. Loading was applied and data were recorded at 20Hz. Peak isometric force generated by the musculature was defined as the maximal load recorded during the test procedure. An average of 3 tests is reported, with a60 second rest period enforced between assessments.

An assessment of cervical musculature fatigue endurance was made using the same test equipment. The player was required to exert an isometric extension load at 50% of their recorded mean peak extension force for as long as possible. The player sat in a neutral position with their arms by their side and head connected to the load cell. Players received visual graphical feedback as to the target load applied via a computer monitor. This allowed for maintenance of a consistent load until failure. A single assessment was made of fatigue.

Anthropometric parameters

Additional measures were made of; height (Leicester Height Measure; SECA, UK), weight (medical grade mechanical flat scales; SECA, UK), grip strength (JAMAR hydraulic hand dynamometer; Sammoms Preston, Illinois, USA) and cervical range of motion (Cervical Range of Motion Instrument, Performance Attainment Associates, Minnesota, USA). Three readings were obtained for each parameter and their average was derived and reported. Prior to the physical assessment, the player's rugby playing history and detail of neck specific training and injuries were determined using a self-reported questionnaire.

Data analysis

Data were analysed using Minitab (Version 16). Data were checked for normality and are reported as means with standard deviation or 95% confidence intervals of the mean as a measure of dispersion. Independent samples t-tests were used to assess differences in continuous variables between groups unless otherwise stated. Significance was accepted as $p < 0.05$ incorporating the Benjami-Hochberg correction for the testing of multiple hypotheses, to reduce the possibility of making a type I error in the interpretation of results.[22, 23]

To assess the secondary research question as to predictive modelling of front row player neck strength all data was considered as a single cohort. Pearson correlation coefficients are reported for bivariate correlations. Stepwise regression modelling was performed to achieve the most predictive model for global neck strength (for which we use isometric extension) utilising the fewest variables. Predictive variables were selected if their bivariate significance was $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables was controlled. A potential limitation of this approach is that the homogenised under-18 group may cause a clustering effect in the data. Separate analysis of the adult data demonstrates the same relationships as reported for the entire cohort lending credibility to the results presented. Further, all players assessed are eligible to play in the adult leagues and can thus be considered representative of a single cohort in the context of our secondary research question; to assess the influence of various physical variables (previously suggested to reflect the variation in cervical strength in a school aged population) in the specific situation of the front row player.

RESULTS

Large differences were observed between groups in terms of age and experience (years) playing as a front row forward. There was no difference in height or grip strength between the groups, though the adults were significantly heavier. Cervical range of motion was similar in measures of extension and rotation, though the elite under-18 group had a greater range of cervical flexion and side flexion (table 1).

Differences were observed in isometric strength between groups in extension (figure 1, table 2) and side flexion (table 2); the under 18 group approximately 20% weaker than the adult group. A larger variation was seen in all parameters of adult neck strength data compared to the under 18 group. This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data, only 2 of the 30 elite under-18 front row players achieved the adult mean strength value (figure 1).

Only 3 of the under-18s achieved the adult mean isometric extension fatigue endurance (impulse, table 2), this difference between groups was significant at $p < 0.1$, possibly reflecting the large variation in adult scores. The adults performed better in the fatigue assessment, holding significantly higher average loads for the same length of time as the younger players (table 2). Surprisingly, only a quarter of all players reported performing routine neck exercises; split evenly between groups (table 1).

Predictive modelling;

Isometric neck strength was most associated with the experience of playing in the front row ($r=0.5$, $p<0.001$) (Figure 2), followed by weight ($r=0.4$, $p=0.004$) and player age ($r=0.4$, $p=0.005$). In contrast, grip strength correlated relatively poorly ($r=0.2$, $p=0.09$) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly (r=0.30, p=0.08). Player weight (r=0.6, p=0.007) was the factor most associated with fatigue, again grip strength correlated poorly (r=0.1, p=0.6).

Stepwise regression determined the best predictive model for isometric strength to include the number of years' experience playing in the front row and the players' weight (table 3). The greatest single contributing variable was the experience of playing in the front row, which explained around 22% of the variation in isometric extension. The same variables also created the best predictive model of fatigue endurance, again explaining around a third of the variation in neck strength (R^2=0.4).

DISCUSSION

This study demonstrates that even elite under-18 front row rugby players, who have participated in a conditioning and strengthening programme, are able to generate significantly less cervical muscle force than adult players. This is relevant when determining the suitability of junior players to compete in the adult game, where significant forces are exerted through the cervical spine of the front row forwards during the scrum. These forces must be modulated by the cervical musculature, and the reduced isometric strength and fatigue endurance ratings found in the under-18 players puts them at a significant disadvantage, with potentially injurious consequences. The under 18 players in this study were the top front row players in Scotland, and this sample of players are most likely to be considered appropriate to play in the adult leagues as they seem physically stronger and bigger. Based on this, it may then be speculated that the difference in neck strength between the general under 18 playing population and adults may be even greater.

Little information is available as to the 'neck strength' of rugby players, either adult or school-aged. We previously assessed the cervical isometric strength of Scottish school children between the ages of 13 and 18 and found huge variation both within and between year groups.[17] We are not aware of any other comparable data for adult players or of any study specifically investigating the cervical isometric strength of the front row forwards. Using multivariate techniques, we previously reported that player age, weight and grip strength (as an objective measure of overall strength) was strongly predictive of isometric neck extension strength in the general school-aged rugby playing population; explaining around two thirds of the variance in cervical strength. Interestingly in this analysis, the measure of grip strength was not a strong predictor of cervical strength in this specific group of front-row players, where player weight and number of years of experience of playing in the front row were the most important factors. This finding may be a reflection of the general lack of neck specific training performed among rugby players. Only 12 of the 64 players reported to have performed any neck specific exercises. This may suggest that the cervical strength of the players in this study were developed from either generic strength training or from specific scrum training. We propose that the elite under-18 players had reached the same global strength as their adult counterparts through peripheral strength training; however in the absence of specific structured conditioning, they could not match the cervical strength the adults had gained as a result of years of competitive scrummaging.

This is to our knowledge the first report of a cervical musculature fatigue endurance assessment in front row rugby players of any age. In the absence of previous data, it was necessary to set a safe threshold at which to perform the test, thus the 50% sub-maximal value was selected to determine reference values for adult and under-18 front row players. While large differences were observed in fatigue endurance values achieved between adult and under-18 players, the large spread of the data in the adult cohort diluted the significance of this finding. Though all players achieved a similar time on fatigue assessment, the 50% sub-maximal load held by the under-18 group (20kg equivalent) was significantly less than the adult 50% load (25kg equivalent), as a result of their lower peak forces on the maximal isometric testing. Now that these benchmark data are available, we recommend that future fatigue endurance assessment of under-18 players should be performed using the mean adult 50% sub-maximal value (25Kg equivalent), which would represent around 60% of the average under-18 maximal isometric value found in this study. It is likely that greater differences would be apparent between adults and under-18 groups had we been able to employ this testing design, and further help discern those able to compete in the adult front row. Future work should also look at assessing 'scrum-specific' fatigue endurance; looking perhaps at repeated bouts of 80% sub-maximal testing over 10-15 seconds which could be argued to better reflect the demands of this activity. We suggest this as an area for future research.

Preatoni et al.[2] assessed the forces generated in the scrum by 34 forward packs at 6 different playing grades (from senior-school to international level) and found notable differences in the forces generated between schools and senior sides. Worryingly, these authors further reported that the combined compression and shear forces they recorded in the scrums were of a sufficient magnitude to induce chronic spine injury. Though further information is needed to understand the link between mechanical forces in the scrum and injury, the shear forces recorded are of particular concern as a risk factor for chronic degeneration of the spine through undesirable rotation and bending motions. The differences in strength characteristics between adult and under-18 players we describe here suggests that appropriate and specific training interventions (perhaps through scrum training) are critical in developing the ability modulate these forces at an individual level.

Perhaps of greater concern is the closed kinetic chain situation of the scrum; where the head is constrained from moving and loads are applied at both ends. This can lead to a buclking motion; a process particularly evident in front row forwards when the scrum collapses and the head strikes the ground. If any single front row player has comparatively weak cervical extensors, it is reasonable to suggest that this may enhance the risk of scrum collapse. We suggest that specific training may influence this, thus younger players and perhaps also those returning from cervical injury are potentially at a competitive disadvantage. For the safety of all six front row players, it is important to recognize, understand and mitigate the biomechanical issues that occur in a closed kinetic chain situation where the forces cannot be vectored away from the spine.

A limitation of this study is the speculative link between cervical strength and scrum collapse and thus injury risk. Although the focus of our investigation was to consider cervical strength parameters, various other factors such as the speed and direction of force application and orientation of the head/neck complex are likely to also have a bearing on the ability to modulate scrum forces. The neutral anatomic position was chosen for strength and fatigue testing from a safety point of view due to the lack of published data to determine alternative test design. The validity of this test position as the optimal assessment profile for rugby cervical testing is unknown. Future work should focus on the influence of head position as to strength and fatigue values in this context. It must also be recognised that recent changes to the laws of the game surrounding scrum engagement, depowering the contact forces at the onset of the scrum and promoting a sustained pushing contest may influence the playing requirements of the cervical spine of the front rows. It may be that endurance parameters are now more critical than absolute strength characteristics, though further work is required to elaborate on any influence to beneficial physical characteristics as a result of this technical change.

In the elite under-18 group assessed, only 2 of 30 players recorded the mean cervical isometric strength of the adult cohort. Although a few individuals may possess the physical characteristics (and technical skill) to compete with adult players, our results suggest that policy should prevent players under the age of 18 playing in the front row of an adult match, unless specific criteria is met. In contrast to the general schoolboy population, predictive modelling of cervical strength using alternative physical characteristics were poor. As such, specific testing would need to be employed to identify those few individuals able to match their adult counterparts in terms of cervical strength. The concept of a passport to play in the front row is well established in some countries as a means of ensuring players are appropriately equipped to cope with the rigours of scrummaging. Objective measures of the individuals' cervical strength profile should be an integral part of any selection process for players wishing to play in the front row.

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AUTHOR CONTRIBUTIONS

All authors listed were involved in the study design and data acquisition. DH performed the analysis and drafted the manuscript. All authors revised and approved the submission.

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CONFLICT OF INTEREST

DG has shares in Gatherer Systems who manufacture and supplied the testing equipment used in this study. The other authors declare no conflict of interest.

DATA SHARING STATEMENT

The data are held in a secure database at the University of Edinburgh. Any party wishing to access unpublished data should discuss with the corresponding author in the first instance.

REFERENCES

[1]. Palmer-Green DS, Stokes KA, Fuller CW, et al. Match injuries in English youth academy and schools rugby union: an epidemiological study. *Am J Sports Med*. 2013;41:749-55.

[2]. Preatoni E, Stokes KA, England ME, et al. The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scand J Med Sci Sports* 2013;23:178-184

[3]. Brooks JHM, Fuller CW, Kemp SPT, et al. Epidemiology of injuries in English Professional rugby union: part 1 match injuries. *Br J Sports Med* 2005:39:757-766

[4]. Brooks JHM, Fuller CW, Kemp SPT,et al. Epidemiology of injuries in English Professional rugby union: part 2 training injuries. *Br J Sports Med* 2005:39:767-775

[5]. McIntosh AS, McCrory P, Finch CF, et al. Head, face and neck injury in youth rugby: incidence and risk factors. *Br J Sports Med* 2010;44:188–193.

[6]. MacLean JG, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great Britain and Ireland. *Br J Sports Med* 2012;46:591-4.

[7]. Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and spinal cord. *Sports Med* 2002;32:633-53

[8]. Brown JC, lambert MI, Verhagen E, et al. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohrot study. BMJ open 2013;3:e002475

[9]. Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players *Br J Sports Med* 2011;45:765–775.

[10]. Gianotti S, Hume PA, Hopkins WG, et al. Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *Br J Sports Med* 2013;42:427-430

[11]. Fuller CW, Brooks JH, Kemp SP. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med*. 2007;17:10-6

[12] Roberts SP, Trewartha G, England M, et al. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* [e-pub ahead of print]

[13]. Scher AT. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clin Sports Med*. 1998;17:195-206

[14]. Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med*. 2012;46:692-3

15]. Nutton RW, Hamilton DF, Hutchison JD, et al. Variation in physical development in schoolboy rugby players: can maturity testing reduce mismatch? *BMJ Open*. 2012;2:e001149

[16]. Torg J, Ramsey-Emrhein J. Suggested management guidelines for participation in collision activities with congenital, developmental, or post injury lesions involving the cervical spine. *Med Sci Sports Exerc*, 1997;29(7):256–272.

[17]. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A cross-sectional cohort study of Scottish schoolchildren. *Bone Joint Res* 2012;1:152–7.

[18]. Garge´s GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc* 2002;33:464-70.

[19]. Jordan A, Mehlsen J, Bu¨low PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine* 1999;24:1343-8.

[20]. Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil* 2002;16:851-8.

[21]. Peek K, Gatherer D. The rehabilitation of a professional rugby union player following a C7/T1 posterior microdiscectomy. *Phys Ther Sport* 2005;**6**:195–200.

[22]. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Statist. Soc.* B 1995;**57**, 289–300.

[23]. Storey JD, "The positive false discovery rate: A Bayesian interpretation and the q-value" *Annals of Statistics* 2003;31: 2013–2035

TABLES

Table 1- Anthropometric data by group

	Under 18	Adult	Significance
Age (years)	16.7 (16-17)	27.2 (19-50)	<0.001[‡]
Experience of the front row (years)	5.0 (1-12)	14.3 (2-26)	<0.001[‡]
Regular neck strengthening (yes/no)	7/23	5/21	0.959[*]
Height (cm)	178.7 (5.54)	178.7 (5.91)	0.960
Weight (kg)	96.0 (13.69)	107.8 (13.67)	0.004[‡]
Grip strength (kg)	47.8 (5.31)	49.56 (7.56)	0.360
Cervical Range of Motion (degrees)			
Extension	65.33 (8.70)	65.62 (6.62)	0.895
Flexion	58.50 (8.32)	44.10 (8.93)	<0001[‡]
Side flexion (left)	49.17 (5.88)	44.33 (6.51)	0.010[‡]
Side flexion (right)	45.60 (8.93)	41.33 (6.18)	0.049
Rotation (left)	66.50 (7.67)	65.90 (6.80)	0.772
Rotation (right)	67.83 (8.06)	64.76 (6.83)	0.149

Age and experience reported as mean (range), all other variables as mean (SD); [‡] Remains significant at the 0.05 level correcting for multiple testing; *Chi Square

Table 2 - Cervical strength assessment by group

	Under 18	Adult	Significance
Isometric Strength (kg)			
Extension	41.70 (39.36, 44.18)	53.70 (48.42, 58.99)	<0.001[‡]
Flexion	22.59 (20.45, 24.72)	25.40 (22.94, 27.86)	0.098
Side flexion (left)	32.24 (30.04, 34.45)	40.53 (36.36, 44.71)	0.002[‡]
Side flexion (right)	31.83 (29.66, 24.01)	42.48 (39.24, 45.73)	<0.001[‡]
Fatigue			
Total (kg.sec)	1305 (1181, 1429)	1551 (1332, 1770)	0.058
Time achieved (sec)	67.10 (60.44, 83.17)	71.81 (62.96, 71.28)	0.390
Average load (kg)	18.25 (16.77, 19.73)	23.54 (21.35, 25.73)	<0.001[‡]

All data reported as mean (95% CI). [‡] Remains significant at the 0.05 level correcting for multiple testing

Table 3 – Multivariate predictive modelling of isometric neck extension (R^2=0.31)

Predictor	Co-efficient	P value

Front row experience	0.63	0.035
Weight	0.22	0.003

Front row experience is the primary predictor variable explaining 22% of the total variation, adding weight as a predictor determines the best fit model (dispoayed above). Other variations offer less than 1% additional enhanced explanatory power with the limitation of comprising more predictor variables and were thus discounted.

FIGURE LEGEND

Figure 1 - Differences in cervical strength by group

Figure 2 – Strong relationship between cervical strength and playing experience

Figure 3 – Weak relationship between grip strength and cervical strength

Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.

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Results: Youth players demonstrated the same height and grip strength as the adult players; however the adults were significantly heavier and demonstrated substantially greater isometric strength ($p < 0.001$). Only 2 of the 'elite' younger players could match the adult mean cervical isometric strength value. In contrast to school age players in general, grip strength was poorly associated with neck strength (r=0.2) in front row players; instead player weight (r=0.4) and the number of years' experience of playing in the front row (r=0.5) were the only relevant factor in multivariate modelling of cervical strength (R^2=0.3).

Conclusions: Extreme forces are generated between opposing front rows in the scrum and avoidance of mismatch is important if the risk of injury is to be minimised. Although elite youth front row rugby players demonstrate the same peripheral strength as their adult counterparts on grip testing, the adults demonstrate significantly greater cervical strength. If older youths and adults are to play together, such findings have to be noted in the development of age group policies with particular reference to the scrum.

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In contrast to general findings on youth players, predictive modelling of cervical strength by proxy measures in this specific group is poor and direct testing is required.

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Age related playing policy should reflect both generic and position specific physical ability

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A particular strength of this study is the direct physical cervical testing of representative player cohorts, and the novel data presented.

A limitation is the assumed though unsubstantiated link between cervical strength and injury; though this is mitigated in this specific context through the known link between scrum collapse and cervical injury.

INTRODUCTION

Rugby Union (henceforth Rugby) is the world's most popular contact, or more appropriately collision~~,~~ sport, and carries an injury risk four times greater than semi-contact sports such as football/soccer.[1] The scrum is an iconic and fundamental part of the game, where two 'forward packs' compete for the ball to restart the game following a minor infringement. It is a test of strength and technique where the cervical spine of the opposing front rows are subjected to huge compressive and shear forces of a sufficient magnitude to result in tissue injury~~[2]~~ and structural failure[2].

Around 8% of all injuries in professional rugby are thought to result from the scrum~~,~~[3, 4]. ~~and r~~Injury events ~~ate~~s in amateur and youth rugby are thought to be similarly proportioned [5]~~,~~. Though 8% represents a comparatively ~~this number is comparatively~~ small proportion of the injury burden, these injuries are likely to be of greater severity and involve the spine.[~~5~~6] Despite a typical match consisting of comparatively few scrums (compared to other contact events, such as tackles), around 40% of all rugby derived acute spinal cord injuries occur in the scrum.[~~6,~~ ~~7~~7, 8] Scrum engagement occurs as the head and shoulders of the competing front rows make forceful contact. The force generated in the scrum engagement~~his~~ is thought to be a particular risk factor for injury, through high compressive and shear loads or hyperflexion of the cervical spine.[~~6-8~~7-9] This risk has been somewhat mitigated in recent years by the introduction of 'controlled scrum engagement' where the distance between opposing front rows has been standardised in an attempt to reduce acceleration and thus collision forces.[~~9,~~ 10, 11] ~~Collapsing of the scrum~~ Scrum collapse has also been identified as a leading cause of scrum related injury.[~~6~~7, ~~11~~12] Premature micro trauma induced degeneration of the cervical spine in front row players[~~12~~~~1~~13] and mismatches in size between front row players[~~6~~7, ~~13~~~~2~~14] have been suggested as potential factors for the over-representation of scrum-related injuries, though Brown et al.[~~7~~8] note that coaching and technical factors have not been well explored in these analyses.

Body size and physical mismatch are considered (at least in part) to be associated ~~to~~ with injury risk in schoolboy rugby.[~~14~~~~3~~15] Some national governing bodies have introduced a weight category banding for youth rugby to address this concern in children who mature skeletally at differing rates. However, once players reach the age of 18 all participants are considered as adults and no such segregation takes place, and the banding rule no longer applies. I~~i~~ndeed rugby is a sport that relies on differing physical attributes for the various playing positions. There are circumstances though where those yet to reach their 18th birthday may wish to play adult rugby, either through selection processes in the case of particularly gifted players, or through leaving school and joining a club playing in the adult leagues. Policy within Scottish Rugby (prior to the start of the 2013-2014 season) had been that only 'exceptional' 17 year-old players were eligible to play in the adult leagues, however, there was concern as to the suitability of this policy regarding the front row.

Though adequate cervical strength is relevant to all rugby players, t~~T~~he scrum exposes player~~'~~s' cervical spines to potentially injurious forces that must be attenuated by controlled spinal motion through the cervical musculature, ligaments and inter-vertebral discs.[~~15~~~~4~~16] Appropriate strength of the cervical musculature is thus particularly important for front row players. The risk of scrum collapse (and by extension associated injuries) is increased if any of the 6 front row players cannot maintain the muscular force required to complete the scrum. The overall compressive and shear forces generated in the scrum are only now being defined. These have been demonstrated to vary by playing level, with youth teams generating significantly lower forces than adult sides[2]. However the relationship between these overall scrum forces and the mechanisms by which the individual front row players modulate them has not been explored. We have previously demonstrated large variation in the neck strength of school-aged rugby players,[~~16~~~~5~~17] however we are not aware of any report of data on maximal strength or fatigue endurance specific to the~~-~~ front row forwards (either youth or adult).~~ ~~Characterisation of the strength profiles of the cervical spine of this specific group is thus warranted.

The aim of this study was to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players to assess the ability of under18 players to compete with adults in the front row of the scrum. A secondary objective was to assess the relationship between isometric strength, and various ~~other ~~physical parameters (such as age, weight and grip strength)~~s~~ previously shown to predict this.

METHODS

Study design and ~~population~~sample

A cross-sectional cohort study was undertaken to investigate the isometric neck strength and fatigue endurance of front row rugby players. Thirty~~30~~ senior school-aged players (under-18 age-grade) were assessed at Murrayfield stadium in tandem with a~~a~~ Scottish Rugby Union (SRU) arranged front row coaching session~~training day~~, and 22 adult players in a separate assessment, again at Murrayfield stadium, organised in conjunction with the SRU.

The youth players were drawn from 21 different clubs/schools from across Scotland and represented the ‘elite’ end of the senior school-aged front row players in Scotland. The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). This range was decided upon to reflect the spectrum of levels that the under-18 group may play. Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams. Both adult and school-age testing sessions took place at the same facility ~~in Murrayfield stadium ~~in the same environment using the same equipment and operators. Participation was voluntary and signed consent was obtained from all participants. Regional Ethics Committee approval was received for this study.

Cervical strength and endurance assessment

Isometric cervical muscle testing is well validated.[~~176-198~~18-20] We assessed maximal voluntary isometric cervical muscle strength with the GS Gatherer and GS Analysis Suite (Gatherer Systems Ltd, Aylesbury); a custom-built device based on a 300Kg load cell and bespoke software system.

The test was performed employing a previously reported protocol[~~165~~17, ~~2019~~21] where the head was placed in the neutral anatomic position and subjected to manual controlled incremental loading to positional failure (the point of head movement). Subject report of pain or neurological symptoms also stopped the test. Loading was applied and data were~~was~~ recorded at 20Hz. Peak isometric force generated by the musculature was defined as the maximal load recorded during the test procedure. An average of 3 tests is reported, with a~~.~~ 60 second rest period enforced between assessments.

An assessment of cervical musculature fatigue endurance was made using the same test equipment. The player was required to exert an isometric extension load at 50% of their recorded mean peak extension force for as long as possible. The player sat in a neutral position with their arms by their side and head connected to the load cell. Players received visual graphical feedback as to the target load applied via a computer monitor. This allowed for maintenance of a consistent load until failure. A single assessment was made of fatigue.

Anthropometric parameters

Additional measures were made of; height (Leicester Height Measure; SECA, UK), weight (medical grade mechanical flat scales; SECA, UK), grip strength (JAMAR hydraulic hand dynamometer; Sammoms Preston, Illinois, USA) and cervical range of motion (Cervical Range of Motion Instrument, Performance Attainment Associates, Minnesota, USA). ~~3~~ Three readings were obtained for each parameter and their average was derived and reported. Prior to the physical assessment, the player's rugby playing history and detail of neck specific training and injuries were determined using a self-reported questionnaire.~~Demographic data and a self-report questionnaire to determine the individual's rugby playing history and details of neck specific training and injuries were completed by the participants prior to physical assessment.~~

Data analysis

Data were analysed using Minitab (Version 16). Data were checked for normality and are reported as means with standard deviation or 95% confidence intervals of the mean as a measure of dispersion. Independent samples t-tests were used to assess differences in continuous variables between groups unless otherwise stated. Significance was accepted as $p < 0.05$ incorporating the Benjami-Hochberg correction for the testing of multiple hypotheses, to reduce the possibility of making a type I~~I~~ error in the interpretation of results.[~~2~~1~~0, 2~~2~~1~~22, 23]

To assess the secondary research question as to predictive modelling of front row player neck strength all data was considered as a single cohort. Pearson correlation coefficients are reported for bivariate correlations. ~~Pearson correlation coefficients are reported for bivariate correlations.~~ ~~Multivariate s~~Stepwise regression modelling was performed to achieve the most predictive model for global neck strength (for which we use isometric extension) utilising the fewest variables. Predictive variables were selected ~~with a~~if their bivariate significance was~~of~~ $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables was controlled. A potential limitation of this approach is that the homogenised under-18 group may cause a clustering effect in the data. Separate analysis of the adult data demonstrates the same relationships as reported for the entire cohort lending credibility to the results presented. Further, all players assessed are eligible to play in the adult leagues and can thus be considered representative of a single cohort in the context of our secondary research question; to assess the influence of various physical variables (previously suggested to reflect the variation in cervical strength in a school aged population) in the specific situation of the front row player.

RESULTS

~~As expected, l~~Large differences were observed between groups in terms of age and experience (years) playing as a front row forward. There was no difference in height or grip strength between the groups, though the adults were significantly heavier. Cervical range of motion was similar in measures of extension and rotation, though the elite under-18 group had a greater range of cervical flexion and ~~rotation~~ side flexion (table 1).

~~Substantial d~~Differences were observed in isometric strength between groups in extension (figure 1, table 2) and side flexion (table 2); the under 18 group approximately 20% weaker than the adult group. A larger variation was seen in all parameters of adult neck strength data compared to the under 18 group. This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data, only 2 of the 30 elite under-18 front row players achieved the adult mean strength value (figure 1~~2~~).

Only 3 of the under-18s achieved the adult mean isometric extension fatigue endurance (~~total work,~~impulse, ~~figure 1~~table 2), this difference between groups was significant at $p < 0.1$, possibly reflecting the large variation in adult scores. The adults performed better in the fatigue assessment, holding significantly higher average loads for the same length of time as the younger players (table 2). Surprisingly, only a quarter of all players reported performing routine neck exercises; split evenly between groups (table 1).

Predictive modelling;

Isometric neck strength was most associated with the experience of playing in the front row (r=0.5, p<0.001) (Figure 2), followed by weight (r=0.4, p=0.004) and player age (r=0.4, p=0.005). In contrast, grip strength correlated relatively poorly (r=0.2, p=0.09) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly (r=0.30, p=0.08). Player weight (r=0.6, p=0.007) was the factor most associated with fatigue, again grip strength correlated poorly (r=0.1, p=0.6).

~~Multivariate~~ Stepwise regression ~~found~~ determined the best predictive model for isometric strength to include the number of years' experience playing in the front row and the players' weight (table 3). The greatest single contributing variable was the experience of playing in the front row, which explained around 22% of the variation in isometric extension. The same variables also created the best predictive model of fatigue endurance, again explaining around a third of the variation in neck strength (R^2=0.4).

DISCUSSION

This study demonstrates that even elite under-18 front row rugby players, who have participated in a conditioning and strengthening programme, are able to generate significantly less cervical muscle force than ~~their~~ adult players~~equivalents~~. This is ~~highly~~ relevant when~~in~~ determining the suitability of junior~~such~~ players to compete in the adult game, where significant forces are exerted through the cervical spine of the front row forwards during the scrum. These forces must be modulated by the cervical musculature, and the reduced isometric strength and fatigue endurance ratings found in the under-18 players puts them at a significant disadvantage, with potentially injurious consequences. The under 18 players in this study were the top front row players in Scotland, and this sample of players are most likely to be considered appropriate to play in the adult leagues as they may seem physically stronger and bigger. Based on this, it may then be speculated that the difference in neck strength between the general under 18 playing population and adults may be even greater.~~A particular concern is that the under-18 players evaluated in this study contained a selection bias of high performance age-grade players. While this group represents the players most likely to be considered appropriate to play in the adult leagues, it is also likely that they are bigger and stronger than their age-grade counterparts, suggesting that the actual difference between the adult and under-18 values in the wider population may be much greater.~~

Little information is available as to the 'neck strength' of rugby players, either adult or school-aged. We previously assessed the cervical isometric strength of Scottish school children between the ages of 13 and 18 and found huge variation both within and between year groups.[~~165~~17] We are not aware of any other comparable data for adult players or of any study specifically investigating the cervical isometric strength of the front row forwards. Using multivariate techniques, we previously reported that player age, weight and grip strength (as an objective measure of overall strength) was strongly predictive of isometric neck extension strength in the general school-aged rugby playing population; explaining around two thirds of the variance in cervical strength. Interestingly in this analysis, the measure of grip strength was not a strong predictor of cervical strength in this specific group of front-row players, where player weight and number of years of experience of playing in the front row were the most important factors. This finding may be a reflection of the general lack of neck specific training performed among rugby players. Only 12 of the 64 players reported to have performed any neck specific exercises. This may suggest that the cervical strength of the players in this study were developed from either generic strength training or from specific scrum training.~~It is likely that for most people scrummaging is the main source of cervical~~

strength training and this is supported by the finding that only a quarter of the players assessed reported performing regular exercises for the neck. We propose that the elite under-18 players had reached the same global strength as their adult counterparts through peripheral strength training; however in the absence of specific structured conditioning, they could not match the cervical strength the adults had gained as a result of years of competitive scrummaging.

This is to our knowledge the first report of a cervical musculature fatigue endurance assessment in front row rugby players of any age. In the absence of previous data, it was necessary to set a safe threshold at which to perform the test, thus the 50% sub-maximal value was selected to determine reference values for adult and under-18 front row players. While large differences were observed in fatigue endurance values achieved between adult and under-18 players, the large spread of the data in the adult cohort diluted the significance of this finding. Though all players achieved a similar time on fatigue assessment, the 50% sub-maximal load held by the under-18 group (20kg equivalent) was significantly less than the adult 50% load (25kg equivalent), as a result of their lower peak forces on the maximal isometric testing. Now that these benchmark data are available, we recommend that future fatigue endurance assessment of under-18 players should be performed using the mean adult 50% sub-maximal value (25Kg equivalent), which would represent around 60% of the average under-18 maximal isometric value found in this study. It is likely that greater differences would be apparent between adults and under-18 groups had we been able to employ this testing design, and further help discern those able to compete in the adult front row. Future work should also look at assessing 'scrum-specific' fatigue endurance; looking perhaps at repeated bouts of 80% sub-maximal testing over 10-15 seconds which could be argued to better reflects the demands of this activity. We suggest this as an area for future research.

Preatoni et al.[2] assessed the forces generated in the scrum by 34 forward packs at 6 different playing grades (from senior-school to international level) and found notable differences in the forces generated between schools and senior sides. Worryingly, these authors further reported that the combined compression and shear forces they recorded in the scrums were of a sufficient magnitude to induce chronic spine injury. Though further information is needed to understand the link between mechanical forces in the scrum and injury, the shear forces recorded are of particular concern as a risk factor for chronic degeneration of the spine through undesirable rotation and bending motions. The differences in strength characteristics between adult and under-18 players we describe here suggests that appropriate and specific training interventions (perhaps through scrum training) are critical in developing the ability modulate these forces at an individual level.

Perhaps of greater concern is the closed kinetic chain situation of the scrum; where the head is constrained from moving and loads are applied at both ends. This can lead to a buclking motion; a process particularly evident in front row forwards when the scrum collapses and the head strikes the ground. If any single front row player has comparatively weak cervical extensors, it is reasonable to suggest that this may enhance the risk of scrum collapse. We suggest that specific training may influence this, thus younger players and perhaps also those returning from cervical injury are potentially at a competitive disadvantage. For the safety of all six front row players, it is important to recognize, understand and mitigate the biomechanical issues that occur in a closed kinetic chain situation where the forces cannot be vectored away from the spine.

A limitation of this study is the speculative link between cervical strength and scrum collapse and thus injury risk. Although the focus of our investigation was to consider cervical strength parameters, various other factors such as the speed and direction of force application and orientation of the head/neck complex are likely to also have a bearing on the ability to modulate scrum forces. The neutral anatomic position was chosen for strength and fatigue testing from a safety point of view due to the lack of published data to determine alternative test design. The validity of this test position as the optimal assessment profile for rugby cervical testing is unknown. Future work should focus on the influence of head position as to strength and fatigue values in this context. It must also be recognised that recent changes to the laws of the game surrounding scrum engagement, depowering the contact forces at the onset of the scrum and promoting a sustained pushing contest may influence the playing requirements of the cervical spine of the front rows. It may be that endurance parameters are now more critical than absolute strength characteristics, though further work is required to elaborate on any influence to beneficial physical characteristics as a result of this technical change.

In the elite under-18 group assessed, only 2 of 30 players recorded the mean cervical isometric strength of the adult cohort. Although a few individuals may possess the physical characteristics (and technical skill) to compete with adult players, our results suggest that policy should prevent players under the age of 18 playing in the front row of an adult match, unless specific criteria is met. In contrast to the general schoolboy population, predictive modelling of cervical strength using alternative physical characteristics ~~were~~ ~~was~~ poor. As such, specific testing would need to be employed to identify those few individuals able to match their adult counterparts in terms of cervical strength. The concept of a passport to play in the front row is well established in some countries as a means of ensuring players are appropriately equipped to cope with the rigours of scrummaging. Objective measures of the individuals' cervical strength profile should be an integral part of any selection process for players wishing to play in the front row.

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AUTHOR CONTRIBUTIONS

All authors listed were involved in the study design and data acquisition. DH performed the analysis and drafted the manuscript. All authors revised and approved the submission.

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CONFLICT OF INTEREST

DG has shares in Gatherer Systems who manufacture and supplied the testing equipment used in this study. The other authors declare no conflict of interest.

DATA SHARING STATEMENT

The data are held in a secure database at the University of Edinburgh. Any party wishing to access unpublished data should discuss with the corresponding author in the first instance.

REFERENCES

[1]. Palmer-Green DS, Stokes KA, Fuller CW, et al. Match injuries in English youth academy and schools rugby union: an epidemiological study. *Am J Sports Med*. 2013;41:749-55.

[2]. Preatoni E, Stokes KA, England ME, et al. The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scand J Med Sci Sports* 2013;23:178-184

[3]. Brooks JHM, Fuller CW, Kemp SPT, et al. Epidemiology of injuries in English Professional rugby union: part 1 match injuries. *Br J Sports Med* 2005:39:757-766

[4]. Brooks JHM, Fuller CW, Kemp SPT,et al. Epidemiology of injuries in English Professional rugby union: part 2 training injuries. *Br J Sports Med* 2005:39:767-775

[5]. McIntosh AS, McCrory P, Finch CF, Wolfe R. Head, face and neck injury in youth rugby: incidence and risk factors. *Br J Sports Med* 2010;44:188–193.

[56]. MacLean JG, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great Britain and Ireland. *Br J Sports Med* 2012;46:591-4.

[67]. Quarrie KL, Cantu RC, Chalmers DJ. Rugby union injuries to the cervical spine and spinal cord. *Sports Med* 2002;32:633-53

[78]. Brown JC, lambert MI, Verhagen E, et al. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohrot study. BMJ open 2013;3:e002475

[89]. Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players *Br J Sports Med* 2011;45:765–775.

[910]. Gianotti S, Hume PA, Hopkins WG, et al. Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *Br J Sports Med* 2013;42:427-430

[1011]. Fuller CW, Brooks JH, Kemp SP. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med*. 2007;17:10-6

[1112] Roberts SP, Trewartha G, England M, et al. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* [e-pub ahead of print]

[12113]. Scher AT. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clin Sports Med*. 1998;17:195-206

[13214]. Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med*. 2012;46:692-3

[14315]. Nutton RW, Hamilton DF, Hutchison JD, et al. Variation in physical development in schoolboy rugby players: can maturity testing reduce mismatch? *BMJ Open*. 2012;2:e001149

[15416]. Torg J, Ramsey-Emrhein J. Suggested management guidelines for participation in collision activities with congenital, developmental, or post injury lesions involving the cervical spine. *Med Sci Sports Exerc*, 1997;29(7):256–272.

[16517]. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A cross-sectional cohort study of Scottish schoolchildren. *Bone Joint Res* 2012;1:152–7.

[17618]. Garge´s GL, Medina D, Milutinovic L, et al. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc* 2002;33:464-70.

[18719]. Jordan A, Mehlsen J, Bu¨low PM, et al. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine* 1999;24:1343-8.

[19820]. Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. *Clin Rehabil* 2002;16:851-8.

[201921]. Peek K, Gatherer D. The rehabilitation of a professional rugby union player following a C7/T1 posterior microdiscectomy. *Phys Ther Sport* 2005;**6**:195–200.

[21022]. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Statist. Soc.* B 1995;**57**, 289–300.

[22123]. Storey JD, "The positive false discovery rate: A Bayesian interpretation and the q-value" *Annals of Statistics* 2003;31: 2013–2035

TABLES

Table 1- Anthropometric data by group

	Under 18	Adult	Significance
Age (years)	16.7 (16-17)	27.2 (19-50)	<0.001‡
Experience of the front row (years)	5.0 (1-12)	14.3 (2-26)	<0.001‡
Regular neck strengthening (yes/no)	7/23	5/21	0.959*
Height (cm)	178.7 (5.54)	178.7 (5.91)	0.960
Weight (kg)	96.0 (13.69)	107.8 (13.67)	0.004‡
Grip strength (kg)	47.8 (5.31)	49.56 (7.56)	0.360
Cervical Range of Motion (degrees)			
Extension	65.33 (8.70)	65.62 (6.62)	0.895
Flexion	58.50 (8.32)	44.10 (8.93)	<0001‡
Side flexion (left)	49.17 (5.88)	44.33 (6.51)	0.010‡
Side flexion (right)	45.60 (8.93)	41.33 (6.18)	0.049
Rotation (left)	66.50 (7.67)	65.90 (6.80)	0.772
Rotation (right)	67.83 (8.06)	64.76 (6.83)	0.149

Age and experience reported as mean (range), all other variables as mean (SD); ‡ Remains significant at the 0.05 level correcting for multiple testing; *Chi Square

Table 2 - Cervical strength assessment by group

	Under 18	Adult	Significance
Isometric Strength (kg)			
Extension	41.70 (39.36, 44.18~~6.74~~)	53.70 (48.42, 58.99~~12.36~~)	<0.001‡
Flexion	22.59 (20.45, 24.72~~5.96~~)	25.40 (22.94, 27.86~~5.76~~)	0.098
Side flexion (left)	32.24 (30.04, 34.45~~6.16~~)	40.53 (36.36, 44.71~~9.76~~)	0.002‡
Side flexion (right)	31.83 (29.66, 24.01~~6.08~~)	42.48 (39.24, 45.73~~7.59~~)	<0.001‡
Fatigue			
Total (kg.~~/~~sec)	1305 (1181, 1429~~236.8~~)	1551 (1332, 1770~~512~~)	0.058
Time achieved (sec)	67.10 (60.44, 83.17~~21.67~~)	71.81 (62.96, 71.28~~9.73~~)	0.390
Average load (kg)	18.25 (16.77, 19.73~~2.82~~)	23.54 (21.35, 25.73~~5.13~~)	<0.001‡

All data reported as mean (95% CI~~SD~~). ‡ Remains significant at the 0.05 level correcting for multiple testing

Table 3 – Multivariate predictive modelling of isometric neck extension (R^2=0.31)

Predictor	Co-efficient	P value

Front row experience	0.63	0.035
Weight	0.22	0.003

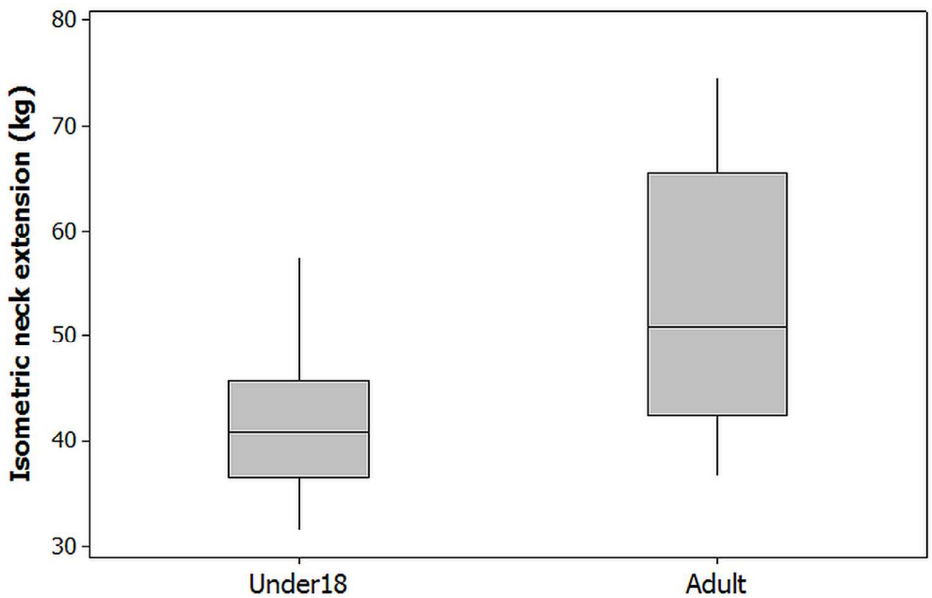
Front row experience is the primary predictor variable explaining 22% of the total variation, adding weight as a predictor determines the best fit model (dispoayed above). Other variations offer less than 1% additional enhanced explanatory power with the limitation of comprising more predictor variables and were thus discounted.

FIGURE LEGEND

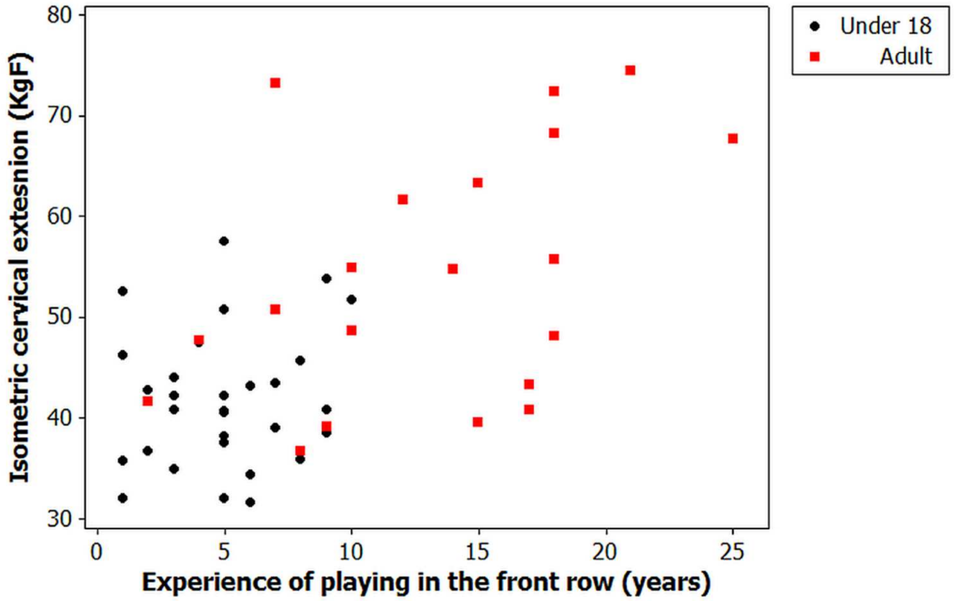
Figure 1 - Differences in cervical strength by group

Figure 2 – Strong relationship between cervical strength and playing experience

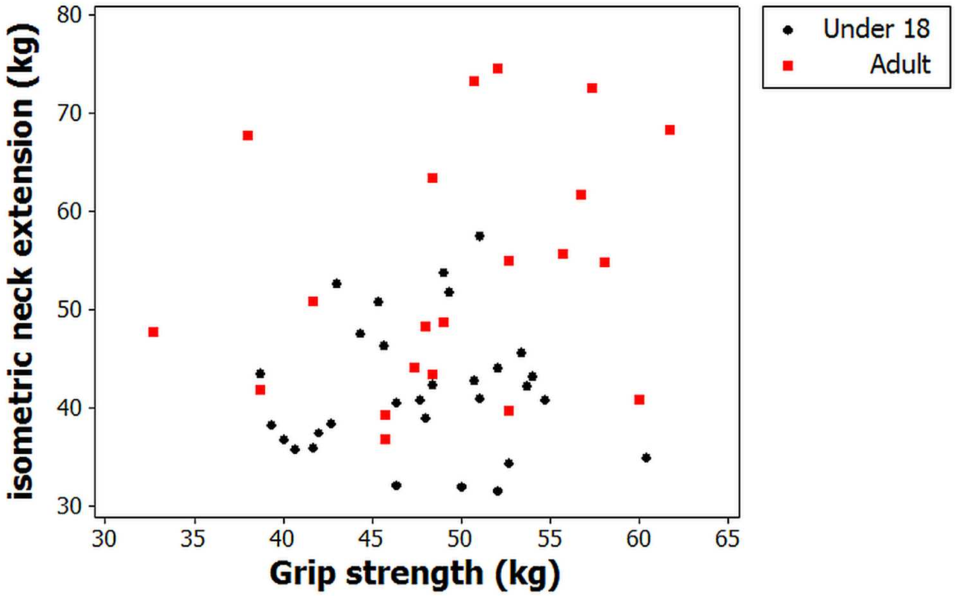
Figure 3 – Weak relationship between grip strength and cervical strength



Differences in cervical isometric extension
90x59mm (300 x 300 DPI)



Strong relationship between cervical strength and playing experience
90x60mm (300 x 300 DPI)



Weak relationship between grip strength and cervical strength
90x59mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	3,4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	4
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	4
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	4
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	4
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	4
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	5
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	6, 7, 8
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	6, 7, 8
Generalisability	21	Discuss the generalisability (external validity) of the study results	8, 9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	9

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.