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ORIGINAL ARTICLE

Endodontic sequelae associated with repetitive impacts to the dentofacial region during boxing activities

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Abstract

Aim: To explore *self-reported* dentofacial trauma and their potential endodontic sequelae in boxers using a questionnaire, followed by clinical and radiographic assessment to (1) compare the nature and number of *self-reported* dentofacial injuries with physical evidence of injury sequelae; and (2) investigate potential risk factors influencing dentofacial trauma and their endodontic sequelae.

Methodology: A focus group validated questionnaire was completed by 176 boxers recruited from 16 London boxing clubs; 61 boxers from this cohort then attended a London dental hospital, for a clinical and radiographic assessment. Data from the questionnaire and clinical assessments were then collated and analysed using Chi-squared or *t*-tests.

Results: Questionnaire data revealed 87.5% of boxers reported a history of dentofacial trauma during boxing activity. The clinical and radiographic assessment detected evidence of dentofacial trauma in 91.8% of boxers and dental injury or endodontic-related injury sequelae in 68.9% of boxers. There was a significant association between dentofacial trauma and boxers who did not participate in weekly neck weight sessions ($p < .001$), and there was a significant association between trauma-related endodontic sequelae and: boxer age ($p = .01$); competitions per month ($p = .002$); and defensive skill ($p = .007$).

Conclusions: A majority of the cohort had suffered dentofacial injuries and endodontic sequelae. The questionnaire data under-reported musculoskeletal injuries and endodontic sequelae, suggesting that some hard-tissue injuries following repetitive dentofacial trauma may have a subclinical presentation. Injury risk may be related to increased boxer age, defensive skills, frequency of participation in competitions, and frequency of neck weight sessions per week.

KEYWORDS

dental trauma, endodontic sequelae, repetitive impact

INTRODUCTION

Dental trauma may be classified under single-event high-impact incidents (Bakland & Andreasen, 2004; Flores et al., 2001) or repetitive lower impact incidents (Bechor & Zadik, 2008). Single-event trauma is characterized by an isolated traumatic event leading to dentofacial tissue injury (Andreasen et al., 1970; Andreasen & Kahler, 2015); it includes a sub-category called "multiple dental trauma episodes", which refers to additional single-event traumatic episodes either to the same tooth or to a different tooth in the same patient (Al-Jundi, 2004; Glendor et al., 2000; Pissiotis et al., 2007). Repetitive impact may cause cumulative injury to the dentofacial region resulting in subclinical *or* chronic pathoses with or without acute exacerbation (Bechor & Zadik, 2008; Porter, 1975; Yeo et al., 2002).

Repeated impact on permanent dentition is common amongst athletes in contact sports (Sane et al., 1988; Zazryn et al., 2006), high-velocity sports (Gassner et al., 1999), musicians (Cremmel & Frank, 1971), and victims of physical abuse (Marcenes et al., 1999). In boxing, the face is a primary impact target for low-grade repetitive dentofacial trauma. The *self-reported* incidence of dentofacial trauma in boxing ranges between 22% and 48% (Ferrari & Ferreria de Mederios, 2002; Ifkovits et al., 2015), whilst studies involving *direct clinical examination* of boxers revealed a higher prevalence (47%–74%) of dentofacial injury (Andrade et al., 2010; Shirani et al., 2010). The discrepancy may be due to the subclinical nature of the associated pathoses (Bechor & Zadik, 2008). Endodontic sequelae associated with single-event trauma have been extensively investigated, although with a focus on paediatric cohorts (Andreasen, 1972; Andreasen et al., 2004; Flores et al., 2001; Forsberg & Tedestam, 1993). Studies investigating adult trauma are comparatively sparse (Lam et al., 2008; Schulman & Peterson, 2004). Sequelae associated with repetitive impact have been scarcely investigated but late-presenting outcomes that differed from those associated with single-event trauma have been reported (Bechor & Zadik, 2008; Cremmel & Frank, 1971). They include *unusual* pulp canal obliteration, root resorption and tooth displacement patterns.

Pathological changes to pulp tissue have also been associated with repetitive application of low-grade continuously dissipating forces during orthodontic tooth movement (Guevara et al., 1977) and beyond the dental discipline in orthopaedic stress-fractures and neurodegenerative disease (Pathria et al., 2016). A recent study reported cranial neurodegenerative disease in soccer players who had experienced repetitive trauma through "heading" the ball (Mackay et al., 2019). Although the fluid dynamics may be different, the high-water content pulp tissue enclosed in a hard dentine "shell" may sustain similar types of disruption when exposed to repetitive trauma. Therefore, the purpose of this study was to investigate the relationship between repetitive, low-grade dentofacial injury and any associated endodontic sequelae. Furthermore, the intention was to compare the prevalence of *self-reported* dentofacial injuries with *clinical* evidence of injury or their sequelae, and to investigate possible risk factors.

MATERIALS AND METHODS

The present study received favourable opinion from the North West – Haydock Research Ethics Committee and the NHS Health Research Authority and Health and Care Research Wakes approval (REC reference 20/NW/0232). The design followed the "strengthening and reporting of observational studies in epidemiology" (STROBE) statement, A flowchart of programme of work is presented in Figure 1.

A focus group-validated questionnaire (Appendices S1 and S2) was created following an interview with three professional and four amateur boxers from London Boxing Clubs in December 2019. All boxers ($n = 186$) from 16 London boxing clubs were invited to participate between June 2020 and August 2020. With pre-arranged club manager approval, the boxers were informed of the study, and a participant information leaflet was circulated to all boxers. At a subsequent date, consented boxers were recruited at their boxing clubs and the questionnaires were completed on-site. The questionnaire was pseudo-anonymised and recorded the boxer demographics, including sex, age, boxing status (amateur/professional), weight division, competition/sparring history, defence strategies, protective wear (mouth guards/head guards), as well as the history of dentofacial trauma and dental attendance.

Between October 2021 and December 2021, after the COVID lockdown, consented boxers attended the Eastman Dental Hospital, University College London, London, UK for a clinical and radiographic dentofacial trauma assessment. The first author (endodontic resident), under the supervision of two endodontists, interviewed and examined all participants following a dental trauma assessment protocol. The clinical assessment included taking a history, completing a tooth-specific assessment on each present tooth/root including pulp tests using an electric pulp tester (SybronEndo Elements Diagnostic, Berkhamsted, UK) and a cold test (Henry Schein Endo Frost Cold Spray, Gillingham, UK). The radiographic assessment included one orthopantomogram (OPG) (Planmeca ProMax®, Helsinki, Finland) and three periapical radiographs of the maxillary incisors and canines using Rinn paralleling devices (Dentsply Limited, Weybridge, UK) and Belmont Phot-X IIS x-ray machine (Takara Belmont Corporationo, Osaka, Japan). The OPG and periapical radiographs were

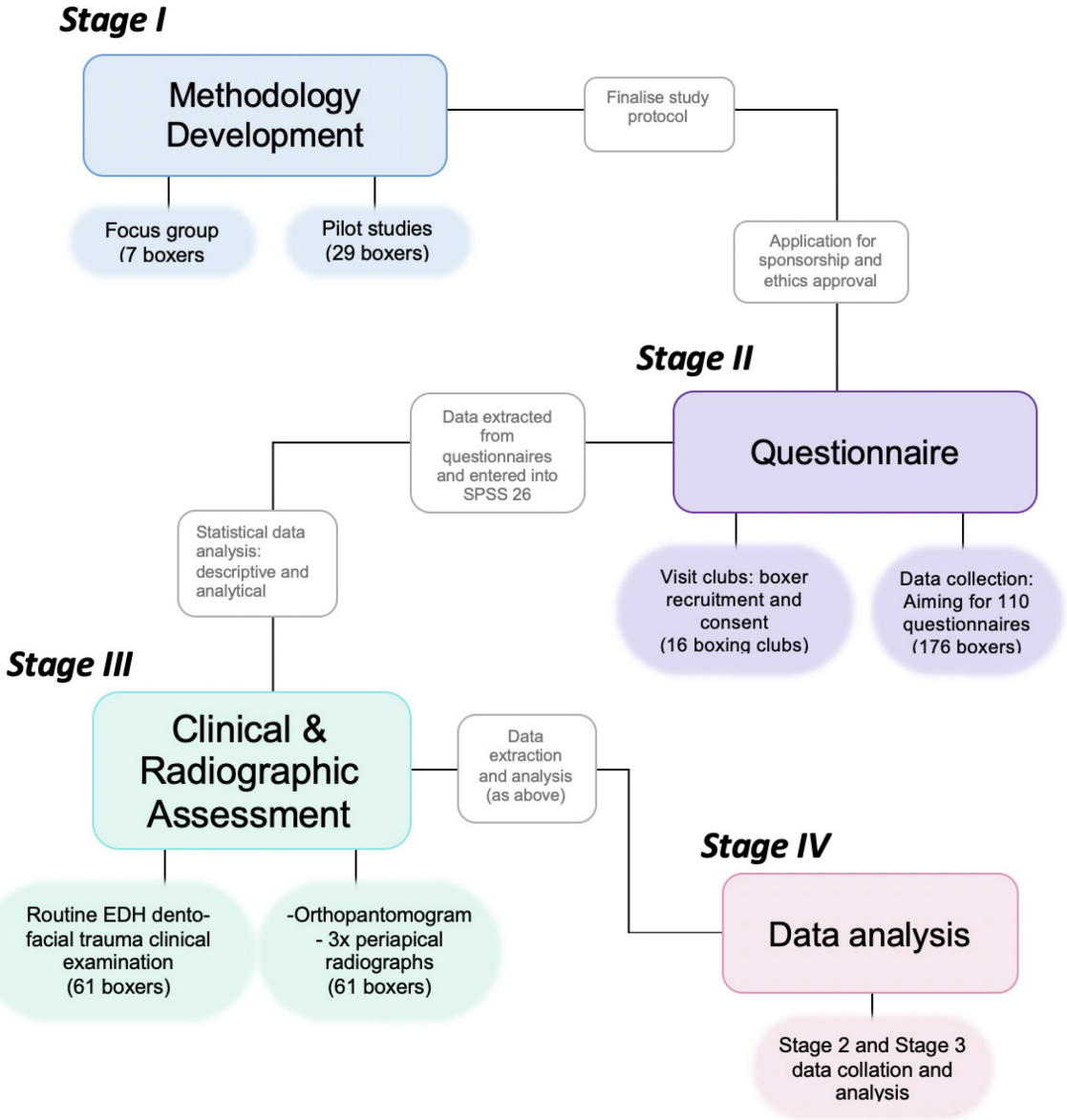

FIGURE 1 Flowchart of programme of work.

processed using PACS software (MediCore, Dallas, TX, USA). Additional CBCT imaging using a Veraview Epocs 3D scanner (J. Morita Manufacturing Corporation, Kyoto, Japan) and posterior periapical radiographs were taken on a case-by-case basis where pathosis was suspected and further information was required for diagnosis, as per the latest International Association of Dental Traumatology Guidelines (Bourguignon et al., 2020). To standardize the radiographic assessments, all periapical radiographs, OPGs, and CBCTs were undertaken by the same dental radiographer, and the pseudo-anonymised images were assessed by a consultant dental radiologist. The assessment was completed in a darkened room using a standardized monitor and the PACS software. A standard assessment protocol was followed, which included screening the temporomandibular joints, condyles, and all permanent teeth. Analysis of the radiographic and CBCT dataset was repeated 4 weeks later by an endodontist using the same monitors, under the same conditions and following the same protocols. The results were calibrated and where discrepancies arose, an independent consultant dental radiologist presided over an agreement.

Data from the questionnaire survey and clinical/radiographic assessments were then collated, summarized, and analysed using the Statistical Package for Social Science version 28.0 (SPSS, IBM Corp. Released 2021, Armonk, NY, USA). The association between dentofacial trauma/trauma-related endodontic sequelae and selected potential influencing factors were analysed using Chi-squared tests. Following assessment at the London dental hospital, boxers who required endodontic or restorative rehabilitation were admitted for dental treatment.

RESULTS

Of a total of 186 invited boxers from 16 London Boxing Clubs, 176 volunteered to participate and completed the questionnaire survey. The boxer demographics and boxing experience are summarized in Table 1. The clinical/radiographic assessment part of the study was ratified to proceed after the COVID lockdown, at which time 61 boxers (Table 1) were available to participate.

Questionnaire survey findings

The questionnaire data from 176 boxers and the subset of 61 boxers who attended clinical and radiographic assessments revealed similar profiles (Tables 1–4).

As expected, a majority (87.5%, $n=154$) of boxers reported a history of dentofacial trauma (Table 4). The frequency distribution of self-reported individual dentofacial trauma injuries is presented in Table 4. The most commonly reported injuries in descending order included: soft tissue cuts or bruising ($n=133$, 75.5%), dental trauma ($n=63$, 37.5%), head concussion ($n=59$, 33.5%), and musculoskeletal trauma ($n=50$, 28.4%) (Table 4).

The location and frequency of self-reported dental injuries are presented in Figure 2. Anterior teeth accounted for 131 injuries, the maxillary incisors were the most frequently injured teeth (tooth 11 accounted for 28 injuries, and tooth 21 accounted for 18 injuries); whilst posterior teeth accounted for 51 injuries.

Clinical and radiographic assessment findings

The clinical and radiographic assessment of the subset of 61 boxers revealed the majority (88.5%) had gingivitis (localized or generalized) and only a small proportion presented with periodontal probing depths greater than 3 mm (11.5%) or clinically detectable dental caries (11.5%) (Table 5). However, dental caries was detected radiographically in 27.9%.

Clinical and radiographic signs and symptoms are indicative of previous dentofacial trauma, and injury sequelae were detected in 91.8% ($n=56$) of boxers. TMJ pain or dysfunction was most prevalent (68.9%, $n=42$), followed by crown fracture (57.4%, $n=35$), apical periodontitis associated with crown fracture (39.3%, $n=24$), pulp canal obliteration (24.6%, $n=15$) (Figure 3), external root resorption manifesting as apical root blunting (19.7%, $n=12$) (Figure 4), tooth discolouration (18%, $n=11$), transient apical breakdown (6.6%, $n=5$) (Figure 5), external cervical or replacement root resorption (both 3.3%, $n=2$) (Figure 6), fractured alveolar bone (3.3%, $n=2$) (Figure 7), cut to the lip/cheek/tongue (1.6%, $n=1$), root fracture (1.6%, $n=1$) (Figure 8) and condensing osteitis (1.6%, $n=1$). Overall, evidence of dental injury or endodontic sequelae was detected in 68.9% ($n=42$) of boxers. The findings are summarized in Table 5.

Potential risk factors associated with a history of dentofacial trauma and its sequelae amongst boxers

The association between potential influencing risk factors and boxers presenting with a history of dentofacial trauma and their sequelae based on both the self-reported questionnaire data and the clinical and radiographic examination data were investigated using Chi-squared tests or *t*-tests. The results are presented in Table 6.

From the questionnaire data, the boxers who self-reported a history of dentofacial traumatic injuries were significantly older ($p=.02$), had participated in the sport

TABLE 1 Questionnaire data: Boxer demographics and boxing experience.

	Total ($n=176$)			Subgroup[a] ($n=61$)		
	Median value/number			Median value/number		
	Amateur ($n=137$)	Professional ($n=39$)	Overall	Amateur ($n=53$)	Professional ($n=8$)	Overall
Age (years)[b]	25.0	33.0	26.0	26.0	38.5	27.0
Sex (number male/female)	107/30	37/2	144/32	40/13	8/0	48/13
Weight (kg)	67.0	74.0	67.0	67.0	83.0	67.0
Length of time in boxing (years)[b]	5.0	10.0	5.0	5.0	11.0	6.0
Sparring sessions (number per week)	2.7	3.0	2.8	3.0	3.0	3.0
Competitions (number per month)	1.0	1.0	1.0	1.0	1.0	1.0

[a]A total of 176 boxers completed the questionnaire, of which a subgroup ($n=61$) attended for clinical and radiographic examinations.

[b]Difference between amateur and professional was significant at the 5% level.

TABLE 2 Questionnaire data: frequency of hit, use/effectiveness of mouthguard and headguard, and defence strategies.

	Total ($n=176$)				Subgroup ($n=61$)			
	Amateur ($n=137$)		Professional ($n=39$)		Amateur ($n=53$)		Professional ($n=8$)	
	n	%	*n*	%	*n*	%	*n*	%
Mouthguard use[a]								
Competition and training	127	93.4	32	82.1	48	90.6	7	87.5
Competition only	2	1.5	2	5.1	1	1.9	0	0.0
Occasionally	4	2.9	3	7.7	3	5.7	1	12.5
Never	3	2.2	2	5.1	1	1.9	0	0.0
Mouthguard type[b]								
Shop bought, not shaped	8	4.5	2	5.1	4	7.6	1	12.5
Shop bought, shaped	107	60.8	27	68.8	44	83.6	5	62.5
Custom-made by dentist	19	10.8	9	22.9	4	7.6	2	25.0
Mouthguard difficulties[b]								
Breathing	18	10.2	6	15.3	10	18.9	1	12.5
Choking	7	4.0	2	5.1	3	5.7	1	12.5
Talking	16	9.1	5	12.7	9	17.0	1	12.5
Cost of custom mouthguard	22	12.5	4	10.2	11	20.8	1	12.5
Headguard wear[a]								
Competition and training	96	54.5	20	51.0	39	73.6	6	75.0
Competition only	7	4.0	1	2.5	6	11.3	0	0.0
Occasionally	23	13.1	11	28.0	4	7.5	1	12.5
Never used	10	5.7	7	17.8	4	7.5	1	12.5
Have you ever injured your teeth or jaw when wearing a mouthguard or headguard[a]								
No	61	44.5	12	30.6	25	47.5	1	12.5
When wearing mouthguard only	34	24.8	19	48.4	8	15.2	5	62.5
When wearing headguard only	5	3.6	0	0.0	2	3.8	0	0.0
When wearing both mouthguard and headguard	36	26.3	8	20.4	18	34.2	2	25.0
Defence strategies to avoid getting hit[b]								
Footwork	134	97.8	38	96.9	53	100.0	8	100
Fade from the punch	134	97.8	38	96.9	53	100.0	8	100
Neck weight training	58	43.1	19	48.4	23	43.7	4	50.0
Mental strength training	35	25.5	20	51.0	16	30.2	3	37.5
Impacts per week[a]								
Median value	10.0		20.2		10.0		20.0	

[a]Single answer only.

[b]Multiple answers possible.

for significantly longer ($p<.001$), and declared more frequent dentofacial impacts per week ($p<.001$) (Table 6). On the other hand, dental trauma or endodontic sequelae were reported significantly more frequently by professional rather than amateur boxers ($p=.03$) and by boxers involved in the sport for a greater length of time ($p=.05$) (Table 6).

The clinical and radiographic data revealed a significant association between boxers who participated more frequently in weekly neck weight sessions, and boxers who presented with signs and symptoms of dentofacial trauma ($p<.001$) (Table 6). Boxers diagnosed with dental or endodontic sequelae were significantly older ($p=.01$), participated in significantly more competitions per month

TABLE 3 Questionnaire data: dental attendance.

	Total ($n=176$)				Subgroup ($n=61$)			
	Amateur ($n=137$)		Professional ($n=39$)		Amateur ($n=53$)		Professional ($n=8$)	
	N	%	*N*	%	*N*	%	*N*	%
Attendance								
Regular attender	55	40.1	16	41.0	16	30.2	2	25.0
Attended in the last 2 years	98	71.5	31	79.5	36	67.9	6	75.0
Reason for check-up								
General check-up	83	60.6	25	64.1	25	48.1	4	50.0
Boxing injury	17	12.4	6	15.4	11	21.2	2	25.0
Radiograph history								
Radiographs in previous 2 years	51	37.2	21	53.8	22	36.1	5	62.5
Reason for radiograph								
General check-up	30	21.9	12	30.8	41	77.4	5	62.5
Pain/treatment	20	14.6	9	23.1	12	22.6	3	37.5

($p=.002$), and self-rated their skills in the defence move "fading from a punch" skills significantly higher ($p=.007$) than those who were diagnosed as injury-free. "Fading from a punch" describes the boxers (self-reported) ability to move their body/head in the direction of the impending blow, thus lessoning the intensity of the received impact.

DISCUSSION

This study represents the first documented analysis of endodontic sequelae associated with repetitive dentofacial impact. Over one billion living people have experienced a dental trauma incident (Petti et al., 2018); stratified data by different types of dentofacial trauma were not available; however, it is likely that a percentage of these injuries will relate to repetitive impact trauma. Whilst boxing was selected as the most ethical way of assessing endodontic sequelae in repetitive impact trauma patient cohorts, the relevance of the study findings may extend to patients who have experienced repetitive dentofacial trauma by other means including those who have experienced repeated domestic/physical violence. The World Health Organization (WHO, 2021) estimates that over 736 million living women have experienced partner/non-partner violence in their lifetime; similar published data for male victims of domestic violence, repeated violent assault, or participation in unlicensed combat (e.g., bare-knuckle boxing) were not available.

The 61-boxer subgroup who attended for clinical and radiographic assessment contained a lower number of professional boxers ($n=8$) than amateur boxers ($n=52$), which reduced the statistical power of the analysis assessing boxer status and dentofacial trauma. It is worth noting, however, that 23% of the "amateur" boxers in the subgroup were training at international and elite levels (4–7 times per week) and thus boxer status may not be as important as boxer age, sparring frequency and years spent boxing.

Endodontic sequelae (including apical periodontitis) of non-traumatic aetiology were excluded as far as possible, by assessing the radiographic data for only teeth with crown fractures, although pulpal/periapical sequelae may arise without crown fractures due to luxation injuries. The prevalence of hard-tissue primary disease (caries) in the present study (28%) was lower than that reported in previous publications assessing dental caries in athletes (49%–55%) (Gallagher et al., 2018; Needleman et al., 2013). The previous studies were based on polyclinic assessments performed at major sporting championships and national training centres; the cross-section of athletes attending for free dental care at such clinics may be influenced by opportunistic infections associated with "peak competition fitness" and resultant immunosuppression, or by socio-economic barriers to dental care access in their home country or locality. Over 68% of boxers exhibited signs of attritive tooth surface loss, whilst 47% had erosive tooth surface loss, which concurs with previous findings on tooth surface loss in athletes (Needleman et al., 2013). Of the boxers who reported repetitive impact dentofacial trauma, only 30.4% had had dental radiographs in the previous 2 years, which falls far below the recommended radiograph review intervals for dentofacial trauma recommended by the IADT 2020 guidelines (Bourguignon et al., 2020).

TABLE 4 Questionnaire data: dentofacial trauma experience.

	Total ($n=176$)				Subgroup ($n=61$)			
	Amateur ($n=137$)		Professional ($n=39$)		Amateur ($n=53$)		Professional ($n=8$)	
	N	%	*N*	%	*N*	%	*N*	%
Soft tissue cut or bruising								
Cut to the lip/cheek/tongue	42	30.7	93	67.9	35	66.0	5	62.5
Bleeding gingivae	47	34.3	22	56.4	20	37.7	5	62.5
Intraoral tissue bruising	10	7.3	1	2.6	9	17.3	1	12.5
Any of above soft tissue injuries	102	54.4	31	79.5	48	90.6	6	75.0
Dental trauma								
Fractured tooth	21	15.3	8	20.5	8	15.1	2	25.0
Loosened tooth	31	22.6	14	35.9	11	20.8	0	0
Tooth knocked out	6	4.4	8	20.8	2	3.8	4	50.0
Any of above dental trauma	42	30.6	21	53.8	15	28.3	4	50.0
Musculoskeletal trauma (including facial bones and TMJ)								
Dislocated jaw	12	8.8	6	15.4	6	11.3	1	12.5
Broken jaw	14	10.2	10	25.6	8	15.1	2	25.0
TMJ pain and dysfunction	14	10.2	10	25.6	5	9.4	3	37.5
Any of above musculoskeletal trauma	33	24.1	17	43.6	14	26.4	4	50.0
Any dentofacial trauma	118	86.1	36	92.3	46	86.8	8	100.0
Head concussion	43	31.4	16	41.0	19	35.8	3	37.5
Occasion of dentofacial trauma								
Training	102	74.5	29	74.4	44	83.0	7	87.5
Competition	44	32.1	20	51.3	14	26.4	4	50.0
Dental trauma sequelae								
No pain or problems after the trauma	43	31.4	16	41.0	13	25.5	2	25.0
Tooth discolouration	10	7.2	7	18.0	3	6.0	2	25.0
Tooth infection	12	8.7	7	18.0	5	10.0	1	12.5
Dentist visit required	19	13.9	6	15.4	5	10.0	1	12.5
Pain following a dentofacial impact								
1–2 weeks	33	24.1	12	30.8	14	28.0	4	50.0
3+ weeks	9	6.6	5	12.9	3	6.3	1	12.5
Any of the above sequelae reported	61	44.5	27	69.2	23	43.4	6	75.0
The same tooth ever injured again	44	32.1	22	56.4	15	29.4	6	75.0
General pain experience regardless of dentofacial trauma (masking effect of other non-dental injuries)								
Pain greater than 5/10 VAS per week	116	79.6	19	74.4	43	80.8	7	87.5
Pain medication	41	30.7	18	46.2	11	20.8	3	37.5

The questionnaire survey revealed that the percentage of boxers (50%, $n=88$) who reported a history of dental trauma sequelae was higher than the 34.5% (Ifkovits et al., 2015) to 35.9% (Emerich & Nadolska-Gazda, 2013; Tulunoglu & Ozbek, 2006) reported in previous questionnaire-based studies on boxers. This may be attributed to the supervised completion of questionnaires in the present study with queries on individual questions clarified spontaneously in real-time, as well as the inclusion of a subsection on endodontic sequelae that was absent in other studies. The clinical and radiographic data detected dentofacial trauma in 91.8% ($n=56$) of boxers, which is higher than figures reported in previous clinical studies on boxers (Andrade et al., 2010; Shirani et al., 2010). Andrade et al. (2010) (73%, $n=19$) did not include a radiographic assessment, whilst Shirani et al. (2010) (47%, $n=14$) did not conform to IADT 2020 guidelines with panoramic and posterior–anterior views

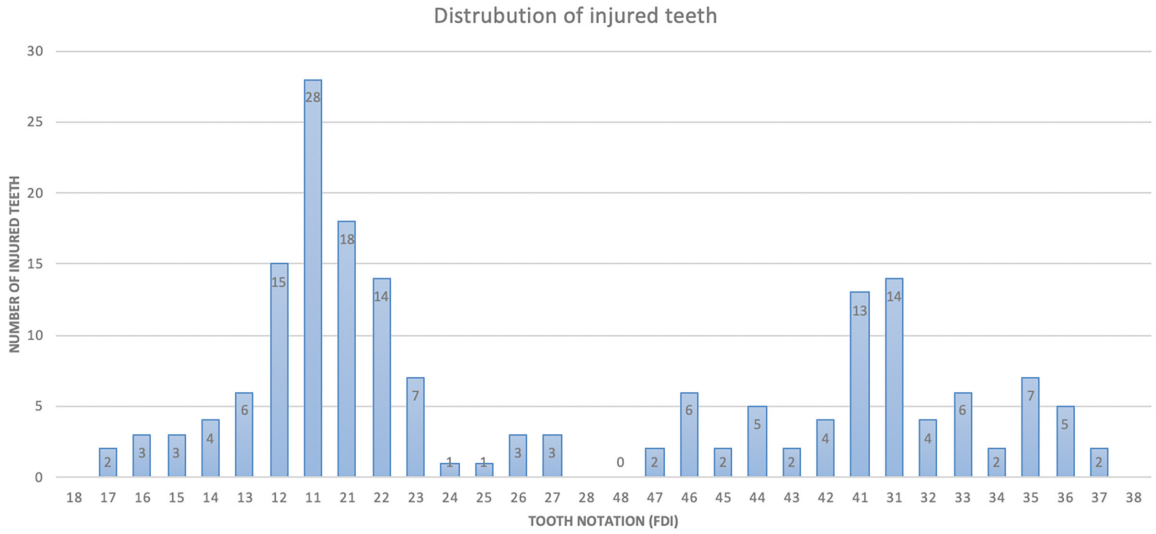

FIGURE 2 Histogram showing the location and frequency of self-reported dental injuries ($n = 176$).

only taken for the mandible and intraoral radiographs not taken.

Although the overall self-assessed (questionnaire data) prevalence of dentofacial trauma (87.5%, $n = 53$) was similar to the clinical and radiographic findings (91.8%, $n = 56$); as expected there was a difference in the nature of the injuries reported between the two datasets. The clinical and radiographic assessment findings revealed that dental trauma or endodontic sequelae (68.9%, $n = 42$) and musculoskeletal injuries (68.9%, $n = 42$) were under-reported by boxers in the questionnaire survey, suggestive of the subclinical nature of these injuries *or* that the boxers took these to be part of the norm for boxing participation and did not consider them to be injuries worth mentioning. The inconsistency may also be attributed to the low sensitivity of questionnaires for detecting dentofacial trauma injuries; the validity of the use of questionnaires in this cohort merits further investigation. There was a significant association between self-reported dental trauma ($p = .02$) or clinically detected endodontic sequelae ($p = .01$) with increasing boxer age, a finding which may be attributed to late presentation of sequelae for hard-tissue injuries *or* older boxers accumulating greater opportunities for cumulative effects. The above findings suggest a need for regular and long-term clinical *and* radiographic assessment of boxers to detect developing subclinical pathoses (IADT 2020 guidelines, Bourguignon et al., 2020).

From the clinical and radiographic data, amateur boxers wearing boil-and-bite (shop-bought) mouthguards were found to be associated with higher prevalence of dental trauma or endodontic-related sequelae compared with those using custom-made mouthguards, albeit such a relationship was only significant at the 10% level; such a finding has not been reported previously. Amongst the present cohort, only a minority (16%) of boxers reported using the custom-made mouthguards, regardless of their status, amateur or professional. Ifkovits et al. (2015) found only 7% of their boxers owned a custom-made mouthguard, with either professional or Olympic status. They also reported that well-fitting mouthguards with customized sport-specific mouthguard thickness were more comfortable and had higher wear compliance, than non-custom mouthguards. Ranalli and Demas (2002) concurred that custom mouthguards offered superior fit and dental injury protection, and that physicians and trainers in the field of sports medicine should exert significant influence over athletes and coaches to promote the benefits of properly fitted custom-fabricated mouthguards to reduce the frequency and severity of orofacial injury. Whilst soft tissue (gingiva periodontium, mucosa) and hard-tissue (enamel, dentine, alveolar bone) injury may be reduced or even eliminated through the use of a well-fitting custom mouthguard (Patrick et al., 2005), the pulp tissue may still sustain vibrational injury and "concussion" in the manner of brain concussion. There may be parallels between pulpal sequelae and neurological degenerative disease of the brain caused by repeated head concussion, since both involve reverberation of soft tissue within a hard non-compliant shell. Systemic review and meta-analysis of the literature have concluded that head protection use does not reduce the risk of head concussion (Benson et al., 2009; Knapik et al., 2019). A similar association between mouthguard use and pulpal sequelae has not been reported but it may be hypothesized that they may not reduce pulpal sequelae. The association between dentofacial trauma and headguard use was not significant, which is as expected; headguards do not protect the dental region. However, the design of headguards for boxing

TABLE 5 Clinical and radiographic examination findings: primary disease, tooth surface loss, previous restorations and root canal treatments ($n = 61$).

	Amateur ($n = 53$)		Professional ($n = 8$)		Total	
	N	%	*N*	%	*N*	%
Primary disease evident						
Gingivitis	46	86.8	8	100	54	88.5
Dental abscess	1	1.9	0	0.0	1	1.6
Probing depth >3 mm	7	13.2	0	0.0	7	11.5
Horizontal bone loss: Radiographic	4	7.5	1	12.5	5	8.2
Dental caries: Clinical	7	13.2	0	0.0	7	11.5
Dental caries: Radiographic	13	24.5	4	50.0	17	27.9
Mean number present (± SD)	1.8	(0.9)	2.0	(1.1)	1.8	(1.0)
Tooth surface loss evident						
Abrasion	3	5.7	1	12.5	4	7.1
Abfraction	9	16.9	3	37.5	12	19.7
Erosion	28	52.8	1	12.5	29	47.5
Attrition	38	71.7	4	50.0	42	68.9
Previous restorations and root canal treatment						
Plastic restoration (if any present)	23	43.4	6	75.0	29	47.5
Mean number present (± SD)	4.3	(3.4)	4.0	(2.5)	3.2	(4.2)
Indirect restoration (if any present)	5	9.4	3	37.5	8	13.1
Mean number present (± SD)	1.8	(1.1)	4.7	(3.5)	2.87	(3.8)
Root canal treatment (if any present)	6	11.3	2	25.0	8	13.1
Mean number present (± SD)	1.7	(1.0)	5.5	(3.5)	2.62	(2.4)
Evidence of previous dentofacial trauma and their sequelae						
TMJ pain or dysfunction	34	64.2	8	100.0	42	68.9
Fractured alveolar bone	1	1.9	1	12.5	2	3.3
Cut to the lip/cheek/tongue	1[a]	1.9	0	0.0	1	1.6
Dental injury or endodontic sequelae						
Tooth discolouration	9	16.9	2	25.0	11	18.0
Pulp canal obliteration	13	24.5	2	25.0	15	24.6
Crown fracture	30	56.6	5	8.2	35	57.4
Root fracture	1	1.9	0	0.0	1	1.6
Apical periodontitis[b]	21	39.6	3	37.5	24	39.3
Condensing osteitis[b]	1	1.9	0	0.0	1	1.6
Root resorption						
External (apical blunting)	10	18.9	2	25.0	12	19.7
External (cervical)	2	3.7	0	0.0	2	3.3
Internal	0	0.0	0	0.0	0	0.0
Replacement	2	3.7	0	0.0	2	3.3
Transient apical breakdown[a]	4	7.5	0	0.0	4	6.6
Ankylosis	0	0.0	0	0.0	0	0.0
Any dental injury or endodontic sequelae	36	67.9	6	75.0	42	68.9
Any dentofacial trauma or sequelae	48	90.6	8	100.0	56	91.8

[a]The participant had traumatic injury 1 day before the examination.

[b]Periapical pathosis associated with crown fracture.

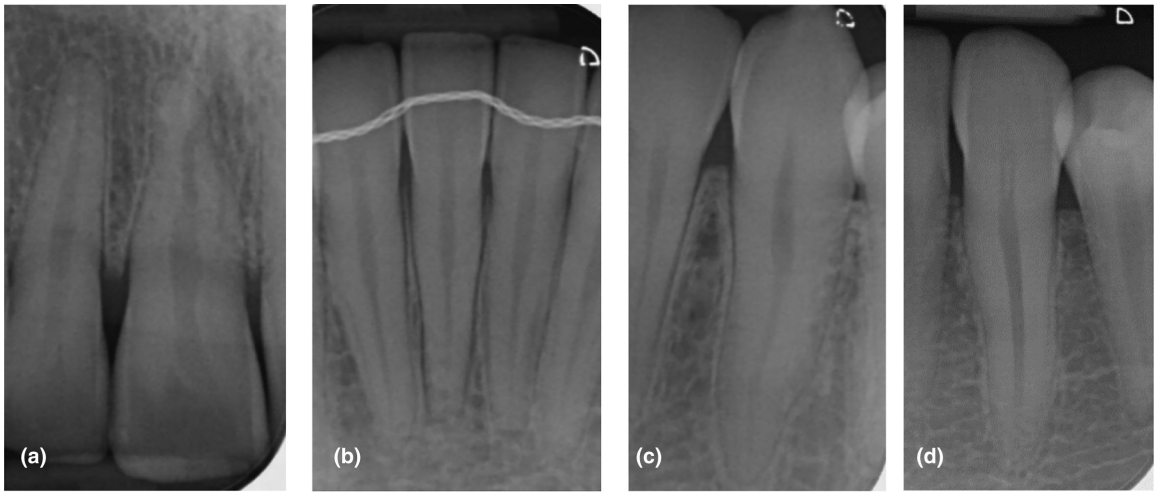

FIGURE 3 (a–c) Examples of irregular intra-canal calcifications in four separate boxers; (d) pulp stone in the LL3.

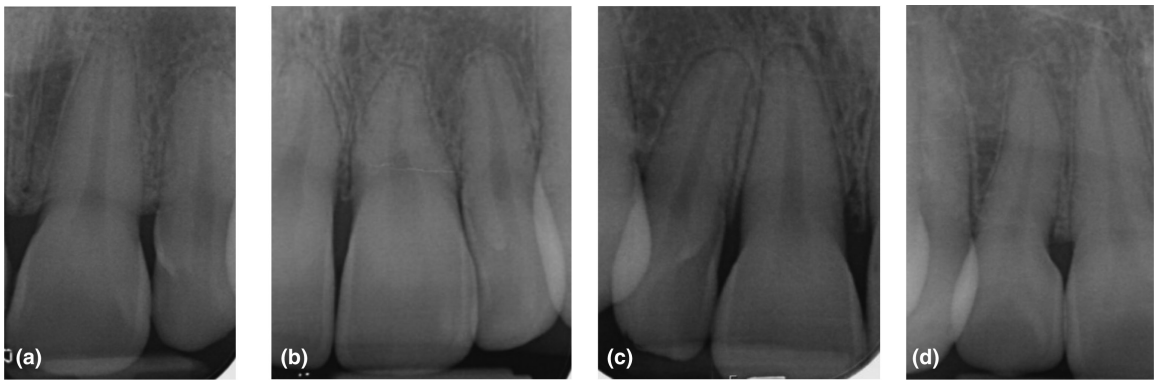

FIGURE 4 (a–d) Examples of apical blunting in patients who had no reported history of orthodontic treatment ($n = 12$).

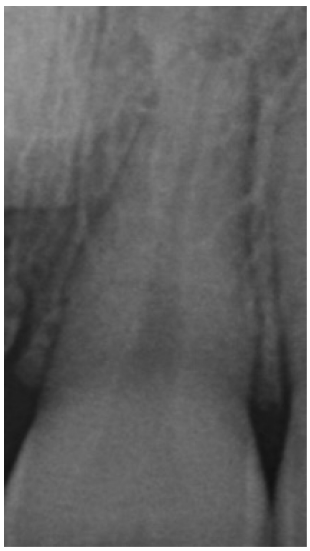

FIGURE 5 Transient apical breakdown.

could be modified to protect the dental region more effectively than mouthguards, potentially reducing the risk of the long-term subclinical dental sequelae.

The present study predictably suggested that boxers can reduce the risk of dentofacial trauma and sequelae by improving defensive strategies such as completing neck weight sessions more frequently ($p < .001$) as well as focusing on fade-punch defensive manoeuvres ($p = .007$). Further exploration of the data revealed boxers who self-reported higher skill levels at "fading from a punch" were older and had more boxing experience than those who reported lower skill levels in such manoeuvres; the older and more experienced boxers were also more likely to self-report experience of dental trauma and their sequelae, which may explain the unexpected findings of this study. Further clinical studies investigating the effects of defence strategies and skills may consider controlling for the above confounding factors. Guidelines for management and follow-up of repetitive dental trauma should be added to the next iteration of the IADT guidelines.

Within the limitations of this study, the questionnaire and clinical and radiograph data revealed that a substantial proportion of boxers presented with sequelae of dentofacial trauma as well as dental problems including gingivitis, caries, tooth surface loss; there is a need to provide further care as well as oral health and dental trauma

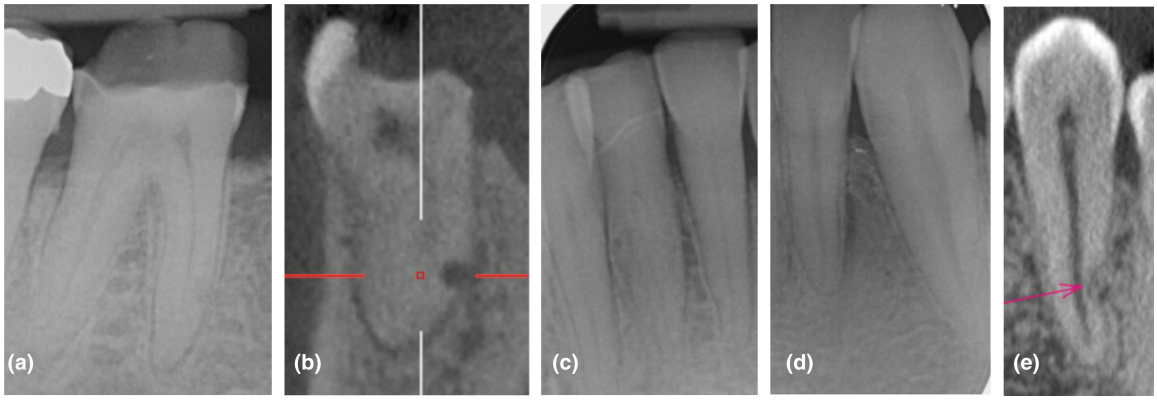

FIGURE 6 Examples of atypical presentation of root resorption in different boxers: (a, b) a small resorptive focus in a posterior first molar; (c) replacement root resorption associated with the lateral border of a LR1; (d, e) replacement resorption associated with the apical lateral border of a LL3.

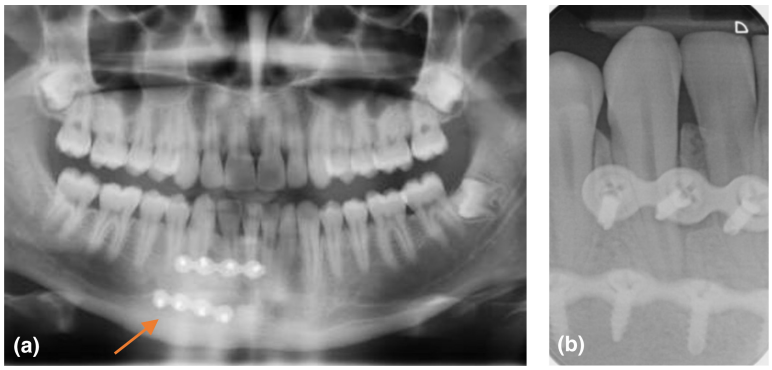

FIGURE 7 (a, b) Fixation plates and screws noted in the right parasymphysis region with the second screw from the right hand and appears to be an intimate relationship with LR3, and possible radiolucency associated with the mesial aspect of LR3 root on the mid-third.

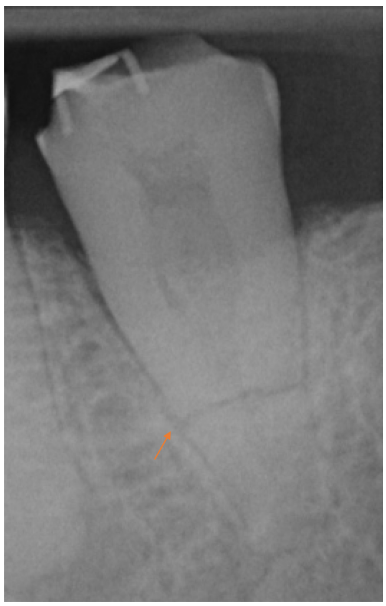

FIGURE 8 Undisplaced root fracture and loss of coronal restoration of LL7 with positive responses to pulp tests and no evidence of periapical pathosis.

education to this cohort. Therefore, following assessment at the London dental hospital, boxers who required endodontic or restorative rehabilitation were admitted for dental treatment. A local trust also offered to reimburse transport costs to and from the hospital for boxers attending for assessment and/or treatment. Additionally, the first author visited the London Boxing Clubs to provide oral health education with a plan to distribute educational posters displaying preventative and dentofacial trauma management advice with an emphasis on the need for long-term dental follow-up under the care of their general dentist.

CONCLUSIONS

A majority of boxers had suffered dentofacial injuries and endodontic sequelae in the studied cohort. The questionnaire data under-reported musculoskeletal injuries and endodontic sequelae, suggestive that some hard-tissue injuries following repetitive dentofacial trauma may have a subclinical presentation as a result of repeated pulpal concussive injury and neural change. Injury risk may be related to increased boxer age, defensive style, frequency of participation in competitions, and neck weight sessions per week. There are no clinical guidelines to advise the management of repetitive dentofacial trauma and injury sequelae, which affects

TABLE 6 Association between potential influencing factors and history of dentofacial trauma and its sequelae based on self-reported questionnaire ($n=176$) and clinical and radiographic examination ($n=61$) findings.

	Questionnaire self-reported data ($n=176$)						Clinical & radiographic evidence ($n=61$)					
	Any dentofacial trauma			Dental trauma or endodontic-related sequelae			Any dentofacial trauma			Dental trauma or endodontic-related sequelae		
Factors	**Yes ($n=154$)**	**No ($n=22$)**	***p*-value**	**Yes ($n=88$)**	**No ($n=88$)**	***p*-value**	**Yes ($n=56$)**	**No ($n=5$)**	***p*-value**	**Yes ($n=42$)**	**No ($n=19$)**	***p*-value**
Boxer group												
Amateur	118 (86%)	19 (14%)	.30	61 (44%)	76 (56%)	.03	48 (91%)	5 (9%)	.6	36 (68%)	17 (32%)	.5
Professional	36 (92%)	3 (8%)	–	27 (69%)	12 (31%)	–	8 (100%)	0 (0%)	–	6 (75%)	2 (25%)	–
Age (year)	29.0 ± 10.5	24.0 ± 7.8	.02	30.8 ± 10.5	24.1 ± 8.8	.1	29.0 ± 10.3	25.0 ± 10.2	.3	30.8 ± 10.5	25.0 ± 6.4	.01
Length of time in boxing (year)	8.5 ± 8.0	3.5 ± 2.3	<.001	9.5 ± 7.9	4.8 ± 6.1	.05	7.4 ± 6.8	4.0 ± 5.7	.2	8.1 ± 6.7	5.9 ± 3.1	.2
Sparring (per week)	2.8 ± 1.3	2.6 ± 1.0	.3	3.0 ± 1.3	2.4 ± 1.2	.09	2.8 ± 1.3	2.4 ± 0.8	.4	2.6 ± 1.2	3.2 ± 1.4	.08
Competition (per month)	1.2 ± 1.3	0.8 ± 1.5	.1	1.3 ± 1.4	0.8 ± 1.2	.1	1.2 ± 1.2	0.5 ± 0.9	.1	0.8 ± 1.0	1.8 ± 1.6	.002
Impacts (per week)	31.7 ± 50.7[a]	10.5 ± 11.1[a]	<.001	36.6 ± 55.9	14.5 ± 21.3	.1	32.5 ± 64.0	5.1 ± 21.8	.2	35.3 ± 26.8	25.5 ± 21.4	.6
Mouthguard use												
Amateur												
Boil/bite	97 (84%)	18 (17%)	.2	51 (53%)	45 (47%)	.2	43 (90%)	5 (11%)	.5	34 (71%)	14 (29%)	.06
Custom	18 (95%)	1 (5%)		7 (37%)	12 (63%)		4 (100%)	0 (0%)		1 (25%)	3 (75%)	
No	3 (100%)	0 (0%)		2 (67%)	1 (33%)		1 (100%)	0 (0%)		1 (100%)	0 (0%)	
Professional												
Boil/bite	26 (90%)	3 (10%)	–	18 (62%)	11 (38%)	.1	6 (100%)	0 (0%)	–	4 (67%)	2 (33%)	–
Custom	9 (100%)	0 (0%)		8 (89%)	1 (11%)		2 (100%)	0 (0%)		2 (100%)	0 (0%)	
No	2 (100%)	0 (0%)		2 (100%)	0 (0%)		0 (0%)	0 (0%)		0 (0%)	0 (0%)	
Mental/Inner strength practice												
Amateur												
Yes	33 (94%)	2 (6%)	.1	20 (57%)	15 (43%)	.1	14 (88%)	2 (13%)	.6	12 (75%)	4 (25%)	.5
No	85 (83%)	17 (17%)		41 (40%)	61 (60%)		34 (92%)	3 (8%)		24 (65%)	13 (35%)	
Professional												
Yes	19 (95%)	1 (5%)	–	16 (80%)	4 (20%)	–	3 (100%)	0 (0%)	–	2 (67%)	1 (33%)	.7
No	17 (89%)	2 (11%)		11 (58%)	8 (42%)		5 (100%)	0 (0%)		4 (80%)	1 (20%)	
Total												
Yes	52 (94%)	3 (6%)	.1	36 (20%)	19 (11%)	.06	17 (89%)	2 (11%)	.6	14 (74%)	5 (26%)	.6

(Continues)

TABLE 6 (Continued)

Factors	Questionnaire self-reported data (n = 176)						Clinical & radiographic evidence (n = 61)					
	Any dentofacial trauma			Dental trauma or endodontic-related sequelae			Any dentofacial trauma			Dental trauma or endodontic-related sequelae		
	Yes (n = 154)	No (n = 22)	p-value	Yes (n = 88)	No (n = 88)	p-value	Yes (n = 56)	No (n = 5)	p-value	Yes (n = 42)	No (n = 19)	p-value
No	102 (84%)	19 (16%)		52 (43%)	69 (57%)		39 (93%)	(7%)		28 (67%)	14 (33%)	
Fading from a punch skill (self-rated 0–10)	6.8 ± 1.7[b]	6.4 ± 1.6	.3	6.9 ± 1.7	6.5 ± 1.8	.1	6.7 ± 1.6	7.3 ± 1.9	.4	6.4 ± 1.6	7.6 ± 1.4	.007
Footwork Skill (self-rated 0–10)	7.0 ± 1.8[b]	6.7 ± 1.4	.5	7.2 ± 1.8	6.6 ± 1.6	.9	7.2 ± 1.6	7.4 ± 1.9	.7	7.2 ± 1.3	7.2 ± 2.3	1.0
Neck weights sessions (per week)	1.0 ± 1.4[a]	0.5 ± 1.5	.08	1.1 ± 1.4	0.7 ± 1.3	.2	1.0 ± 1.4	0.1 ± 1.0	<.001	0.9 ± 1.5	1.0 ± 1.2	.8
Dental attendance (per year)	0.7 ± 0.5[a]	0.8 ± 0.4	.3	0.7 ± 0.4	0.7 ± 0.4	.6	0.7 ± 0.5	0.6 ± 0.5	.5	0.7 ± 0.5	0.7 ± 0.5	1.0

Note: *p*-value for Chi-squared test = boxer group, dental attendance, neck weight sessions; *p*-value for *t*-tests = age, length of time in boxing, sparring, competition, impacts, fading from a punch skill, footwork skill.

[a]1 missing data.

[b]4 missing data.

many sporting *and non-sporting* patient cohorts including victims of domestic violence and repeated violent assault; further research may facilitate inclusion in the next iteration of the IADT guidelines.

AUTHOR CONTRIBUTIONS

Sally McCarthy: Conceptualization (equal); Data curation (lead); Formal analysis (equal); Investigation (lead); Methodology (lead); Visualization (equal); Writing – original draft preparation (lead); Writing – review and editing (supporting). **Kishor Gulabivala:** Conceptualization (equal), Methodology (equal); Supervision (equal), Visualization (equal), Writing – review and editing (supporting). **Geoffrey St. George:** Conceptualization (equal); Methodology (supporting); Investigation (supporting). **Simon Harvey:** Methodology (supporting); Investigation (supporting); Validation (equal). **Yuan-Ling Ng:** Conceptualization (equal); Formal analysis (equal); Methodology (equal); Supervision (equal); Validation (equal); Visualization (equal); Writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. We certify that the submission is original work and is not under review at any other publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, [Y-LN]. The data are not publicly available due to restrictions e.g. their containing information that could compromise the privacy of research participants.

ETHICS STATEMENT

A favourable ethical opinion was given by North West - Haycock Research Ethics Committee (IRAS: 272721, Study Number: 20/NW/0232), and by HRA and Health and Care Research Wales. The UCLH JRO Covid-19 committee approved non-UCLH site data collection only following Covid-19 related UCLH research restrictions.

PATIENT CONSENT STATEMENT

Written consent was obtained from all boxers who volunteered to participate in this study. Boxers were informed about the nature of the questionnaire, clinical and radiographic examination and given the “Patient Information Sheet”, and “Consent Form” to consider and consent

by signing. All potential participants were given at least 1 week to consider taking part. Boxer participation in the clinical/radiographic examination was contingent upon written consent from the boxer's general dental practitioner (submission of a proforma referral letter). Boxers who attend for clinical and radiographic examination at the Eastman Dental Hospital are required to sign a secondary routine clinical consent upon arrival, as per UCLH protocol.

PERMISSION TO REPRODUCE MATERIAL FROM OTHER SOURCE

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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