Research Article

Quality reporting of carotid intima-media thickness methodology; Current state of the science in the field of spinal cord injury

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Objectives: Carotid intima-media thickness (cIMT) may be used increasingly as a cardiovascular disease (CVD) screening tool in individuals with spinal cord injury (SCI) as other routine invasive diagnostic tests are often unfeasible. However, variation in cIMT acquisition and analysis methods is an issue in the current published literature. The growth of the field is dependent on cIMT quality acquisition and analysis to ensure accurate reporting of CVD risk. The purpose of this study is to evaluate the quality of the reported methodology used to collect cIMT values in SCI.

Methods: Data from 12 studies, which measured cIMT in individuals with SCI, were identified from the Medline, Embase and CINAHL databases. The quality of the reported methodologies was scored based on adherence to cIMT methodological guidelines abstracted from two consensus papers.

Results: Five studies were scored as '*moderate quality*' in methodological reporting, having specified 9 to 11 of 15 quality reporting criterion. The remaining seven studies were scored as '*low quality*', having reported less than 9 of 15 quality reporting criterion. No study had methodological reporting that was scored as '*high quality*'. The overall reporting of quality methodology was poor in the published SCI literature.

Conclusions: A greater adherence to current methodological guidelines is needed to advance the field of cIMT in SCI. Further research is necessary to refine cIMT acquisition and analysis guidelines to aid authors designing research and journals in screening manuscripts for publication.

Keywords: Atherosclerosis, Spinal cord injury, Carotid intima-media thickness, Tetraplegia, Paraplegia, Cardiovascular disease

Introduction

Individuals with chronic spinal cord injury (SCI) are at an increased risk of developing cardiovascular disease (CVD) compared to their age- and sex-matched counterparts in the general population.^{1,2} One non-invasive and practical measurement tool that is used to quantify CVD risk in both the general and SCI populations is carotid intima-media thickness (cIMT). CIMT is defined as the distance between the lumen-intima and media-adventitia interfaces of the common carotid artery (CCA) as measured via ultrasonography (Fig. 1).^{3,4} Since cIMT was first measured by Pignoli *et al.* in 1986,⁵ it has been increasingly used as a non-invasive surrogate measure of atherosclerosis.⁶ The carotid artery is the primary site for obtaining IMT measurements in both research and clinical settings. The anatomical position of the carotid artery allows

for convenient image collection,⁷ and absolute cIMT increases of 0.1 mm correlate with: (i) a 10% to 15% increase in myocardial infarction risk; and (ii) a 13% to 18% increase in stroke risk in the able-bodied population.⁶ As CVD is especially prevalent in individuals with SCI, and routine invasive diagnostic tests are often infeasible or difficult to interpret, cIMT measurement may be used increasingly as a CVD screening tool among individuals with chronic SCI.

Obtaining cIMT values is generally a two-step process involving carotid artery image acquisition by B-mode ultrasound, followed by cIMT analysis using specialized software to obtain measurements.

Although international guidelines do not exist regarding cIMT as a research tool,⁸ cIMT acquisition and analysis guidelines have been developed by the American Society of Echocardiography cIMT task force (2012) as well as the Advisory Board for the 'watching the risk symposia' at the European Stroke Conferences (2011).^{4,9} However, despite publication of

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Figure 1 Carotid artery ultrasound image showing the double-line pattern used to measure carotid intima-media thickness (cIMT).

these guidelines, standardization of cIMT methods across studies has been identified as a major priority to advance the field and allow for data synthesis and meta-analyses.¹⁰ A review of cIMT study design and data analysis in the able-bodied population revealed that optimal approaches are very much determined by the research question at hand and the population under examination.¹¹ It is currently unclear to what extent the SCI field has adopted these cIMT standards, further, given the nature of SCI, there are legitimate physiological reasons why quality cIMT methods may be challenging to implement in this population compared to the general population. These challenges aside, however, adherence to current methodological guidelines is needed to ensure accurate reporting of CVD risk and advance the field of cIMT research in SCI. A previous review conducted by Stoner *et al.* (2015) included cIMT among a list of vascular health tools recommended for routine assessment of CVD in SCI.¹² Stoner mentioned that although the measurement protocols may considerably influence the reported cIMT values, when a standardized protocol is coupled with automated image analysis software, carotid IMT assessments are highly objective and reliable.

In accordance with the strengthening the reporting of observational studies in epidemiology or STROBE statement, detailed methods of assessments should be clearly outlined in observational studies.¹³ Recognizing and standardizing how cIMT data should be collected and presented will be increasingly important for advancement of cIMT for CVD screening.

In this study, the quality of the cIMT methodology reporting in the current published literature relating to cIMT measurement in individuals with chronic SCI

will be examined and compared to the guidelines put forth by the abovementioned consensus papers.^{4,9} Furthermore, the cIMT measurement issues highlighted in these studies will be discussed.

Methods

Literature search

An electronic search of Medline, Embase and CINAHL (1947–February 2016) was performed for the following search criteria: ‘spinal cord injuries’ OR ‘spinal cord injury’ OR ‘paraplegia’ OR ‘quadriplegia’ AND ‘carotid intima-media thickness’ OR ‘tunica intima’ OR ‘tunica media’ OR ‘carotid arteries’ OR ‘arterial wall thickness’ OR ‘CCA-IMT’ as a text word, among other related terms. All identified abstracts and titles were screened for relevance to the search inclusion criteria. The full texts of relevant articles were reviewed. The selected studies met inclusion criteria if they included participants with SCI, and cIMT methods were described. The identified studies were limited to the English language and conference abstracts were excluded. The initial search yielded 28 articles. After review of the selected articles and hand searching of the reference lists, this list was reduced from 28 to 12 articles for appraisal of methodological quality related to cIMT acquisition and analysis.

Appraising cIMT method quality

A set of criteria, formatted as questions, were developed to assess the quality of the cIMT acquisition and analysis method reporting in the publications identified during the search. The authors examined two cIMT consensus papers; statements from the American Society of Echocardiography (ASE) and the Mannheim Carotid Intima-Media Thickness and Plaque Consensus Advisory Board (MCAB),^{4,9} and developed a related quality checklist specifying criteria for quality method reporting from both of the aforementioned consensus papers. Clinical criteria were incorporated into the quality checklist if the criteria were agreed upon in both consensus papers or if a criterion was flagged or discussed by one of the previously published consensus papers. In cases where the two consensus papers differed with regards to a specific criterion, both criteria were incorporated. In total, a 15-item checklist outlining quality methods for cIMT acquisition and analysis, was developed (Table 1). Data from the identified publications were abstracted and scored using the 15-item checklist. Double data abstraction was performed to avoid bias in study result interpretation by two investigators (JH and MM). Discordance between abstractors was resolved by a third investigator (CC). Each numbered question (or

Table 1 CIMT quality methodology checklist.

	Source of question
<i>Acquisition strategy</i>	
1) Are arteries imaged using B-mode ultrasound with a linear-array transducer operating at frequencies > 7 MHz?	■
2) Is the distal CCA used?	■
3) Is only the far wall used?	■
4) Are the left & right sides both used?	■
5) Is the distance measured between the leading edges of the media-adventitia and intima-lumen interfaces	■
6) Is CCA lumen diameter measured?	■ ^a
7) Is CCA inter-adventitial diameter measured?	■ ^a
8) Is/are angle(s) of insonation specified?	
a. Lateral	■
b. Multiple	□
<i>Analysis</i>	
9) Measurement system	
a. Is the measurement system specified?	■
b. Is a semi-automatic or automatic ⁺ measurement system used?	□
10) Are IMT measurements taken at end diastole?	■
11) IMT calculation	
a. Is the calculation method clearly reported (ie. mean-mean, mean-max)?	■
b. Is the method of CIMT measurements specified as mean-mean?	□
12) Are carotid plaque findings discussed?	■
13) Is data variability evaluated using an intra-class correlation coefficient?	■ ^a
<i>Additional reporting</i>	
14) Is assessor training or skill level specified?	■
15) Are demographics included?	□ ^b

□ American Society of Echocardiography (ASE),

■ Mannheim Consensus Advisory Board (MCAB),

■ ASE & MCAB, ^aTopic not discussed by the ASE, ^bTopic not discussed by MCAB.

quality criterion) was worth one point for a total of 15 points. The total points were then converted to a percentage out of 100. Items 8, 9 and 11 had two criteria for which studies received a score of one if they met either of the two quality criteria. If a study's methodology met neither criterion for items 8, 9 and 11, a score of zero was assigned.

Identifying quality

Studies specifying 12 of 15 quality criteria (80%+) were scored as '*high quality*' in methodological reporting. A study was labelled '*moderate quality*' if 9 to 11 criteria (60–73%) were specified. Studies reporting less than 9 of the 15 quality reporting criteria (<60%) were scored as '*low quality*'. These thresholds were arbitrarily developed by the authors based on face validity without psychometric validation.

Results

A total of 12 studies met inclusion criteria and were selected for review (Fig. 2). Based on our search strategy and as shown in Table 2, the majority of the published literature was cross-sectional in nature (10/12),^{14–23} with two prospective observational studies.^{24,25} The majority of studies have small sample sizes, with three notable

exceptions with samples of more than 100 individuals with SCI. The majority of studies (9/12; 75%) examined among individuals with chronic SCI (≥2 years).

Acquisition

As shown in Table 3, acquisition location, including arterial segment, wall, side and distance were all well

Figure 2 Flow diagram for the review of carotid intima-media thickness measurement in the spinal cord injury population, 1947- February 2016.

Table 2 Overview of cIMT study methods.

	Bell <i>et al.</i> (2011) ¹⁴	Jae <i>et al.</i> (2008) ¹⁵	Matos- Souza <i>et al.</i> (2009) ¹⁶	Matos- Souza <i>et al.</i> (2010) ¹⁷	Matos- Souza <i>et al.</i> (2013) ¹⁸	Matos- Souza <i>et al.</i> (2015) ²⁴	Paim <i>et al.</i> (2013) ¹⁹	Rowley <i>et al.</i> (2012) ²⁰	Schmidt- Trucksass <i>et al.</i> (2000) ²¹	Szlachcic <i>et al.</i> (2014) ²²	Thijssen <i>et al.</i> (2012) ²⁵	Wang <i>et al.</i> (2009) ²³
Study design												
Study design	CS	CS	CS	CS	CS	PO	CS	CS	CS	CS	PO	CS
Sample size	261	52	50	65	82	17	58	52	51	122	8	172
Sample with SCI	105	28	23	34	54	17	42	14	10	122	8	110
SCI demographics												
Sex (% male)	88.7	60.7	100	100	100	100	100	100	100	0	100	100
Age (years)	40.7 ± 10.8	22.0 ± 3.0	31.8 ± 1.4	31.9 ± 1.3	30.5 ± 1.8	31.2 ± 3.6	31.0 ± 1.9	38.6 ± 11.0	38.5 ± 6.8	43.1 ± 11.1	35.0 ± 14.0	39.6 ± 10.1
Years post-injury	19.2 ± 8.9	N.S	7.4 ± 0.9	6.7 ± 0.8	8.5 ± 1.3	6.4 ± 1.9	8.4 ± 1.4	N.S	11.4	16.4 ± 10.8	3–24 wks	12.0 ± 6.9
Neurological level	% Para AIS A-D	N.S	56.5	47.1	51.9	47.1	52.4	N.S	100	69.7	100	48.2 ^a
	%Tetra AIS A-D	29.5	43.5	52.9	48.1	52.9	47.6		0	30.3	0	51.8 ^b
cIMT acquisition												
Segment	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA	Distal CCA
Wall(s)	Far	Far	Far	Far	Far	Far	Far	Far	Far	Far	both	N.S
Side(s)	N.S	Both	Both	Both	Both	Both	Both	N.S	Right	Right	Left	Both
cIMT Analysis Method	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto	N.S	Auto	Auto	N.S

^a T-7 or below; ^b T-6 or above; CS cross sectional; PO prospective observational; N.S Not specified

Table 3 Adherence of published IMT research to consensus published guidelines from the American Society of Echocardiography and Mannheim Consensus Advisory Board.

	Source of question	Bell <i>et al.</i> (2011) ¹⁴	Jae <i>et al.</i> (2008) ¹⁵	Matos-Souza <i>et al.</i> * (2009) ¹⁶	Matos-Souza <i>et al.</i> (2010) ¹⁷	Matos-Souza <i>et al.</i> * (2013) ¹⁸	Matos-Souza <i>et al.</i> (2015) ²⁴	Paim <i>et al.</i> (2013) ¹⁹	Rowley <i>et al.</i> (2012) ²⁰	Schmidt-Tucksass <i>et al.</i> (2000) ²¹	Szlachcic <i>et al.</i> (2014) ²²	Thijssen <i>et al.</i> (2012) ²⁵	Wang <i>et al.</i> (2009) ²³	Percentage of studies reporting quality methods
Acquisition strategy														
1) Are arteries imaged using B-mode ultrasound with a linear-array transducer operating at frequencies > 7 MHz?	■		X	X	X	X	X	X	X		X			67%
2) Is the distal CCA used?	■	X	X	X	X	X ^{>}	X	X	X	X	X	X	X	100%
3) Is only the far wall used?	■	X	X	X	X	X ^{>}	X	X	X	X	X			83%
4) Are the left & right sides both used?	■		X	X	X	X ^{>}		X					X	50%
5) Is the distance measured between the leading edges of the media-adventitia and intima-lumen interfaces	■	X	X	X	X	X ^{>}	X ^{>}	X	X	X	X	X		92%
6) Is CCA lumen diameter measured?	■ ^a	X			X	X	X	X	X	X		X		67%
7) Is CCA inter-adventitial diameter measured?	■ ^a													0%
8) Is/are angle(s) of insonation specified?														
b. Lateral	■													0%
b. Multiple	□								X					8%
Analysis														
9) Measurement system														
c. Is the measurement system specified?	■	X	X	X	X	X	X	X	X		X	X		83%
d. Is a semi-automatic or automatic ⁺ measurement system used?	□	X	X	X	X	X	X	X	X		X	X		83%
10) Are IMT measurements taken at end diastole?	■		X											8%
11) IMT calculation														

Continued

Table 3 Continued

	Source of question	Bell <i>et al.</i> (2011) ¹⁴	Jae <i>et al.</i> (2008) ¹⁵	Matos-Souza <i>et al.</i> * (2009) ¹⁶	Matos-Souza <i>et al.</i> (2010) ¹⁷	Matos-Souza <i>et al.</i> * (2013) ¹⁸	Matos-Souza <i>et al.</i> (2015) ²⁴	Paim <i>et al.</i> (2013) ¹⁹	Rowley <i>et al.</i> (2012) ²⁰	Schmidt-Tucksass <i>et al.</i> (2000) ²¹	Szlachcic <i>et al.</i> (2014) ²²	Thijssen <i>et al.</i> (2012) ²⁵	Wang <i>et al.</i> (2009) ²³	Percentage of studies reporting quality methods
c. Is the calculation method clearly reported (ie. mean-mean, mean-max)?	■		X								X ^{>}	X	X	33%
d. Is the method of CIMT measurements specified as mean-mean?	□										X	X		17%
12) Are carotid plaque findings discussed?	■			X	X			X		X			X	42%
13) Is data variability evaluated using an intra-class correlation coefficient?	■ ^a		X										X	17%
Additional reporting														
14) Is assessor training or skill level specified?	■				X	X ^{>}	X	X	X					42%
15) Are demographics included?	□ ^b	X	X	X	X	X	X	X	X	X	X	X	X	100%
Reporting frequency of each quality methods element		40%	67%	53%	67%	60%	53%	67%	60%	40%	46%	40%	40%	
Quality reporting category		Low	Mod.	Low	Mod.	Mod.	Low	Mod.	Mod.	Low	Low	Low	Low	

□ American Society of Echocardiography (ASE), ■ Mannheim Consensus Advisory Board (MCAB), ■ ASE & MCAB, * Letter to the editor, ^a Topic not discussed by the ASE, ^b Topic not discussed by the MCAB, [>] Referenced to another study, *Note: Where questions are divided into multiple parts (8, 9, 11), the question is counted as one in percentage calculations if either or both parts are fulfilled.*

documented in the published literature. All twelve studies (100%) measured cIMT at the distal CCA as recommended by the consensus papers. Eleven of twelve studies (92%) specified that cIMT was measured between the leading edges of the media-adventitia and intima-lumen interfaces,^{14–22,24,25} as recommended by both consensus papers. The specific CCA wall and side used were more variable, with ten of twelve (83%)^{14–22,24} and six of twelve (50%)^{15–19,23} studies reporting methods aligning with guidelines, respectively. Ultrasound equipment specifications including mode, transducer type and frequency were reported in eight of twelve studies (67%).^{15–20,22,24} Three of the remaining four studies also reported specifications regarding the ultrasound equipment, but provided frequency ranges that straddled the minimum requirement provided by the ASE and MCAB statements.^{14,23,25} One study did not specify that B-mode ultrasound was used.²¹ Angles of insonation were specified in a single study by Rowley *et al.*²⁰

Analysis

Table 3 also shows that the measurement system was specified in ten of twelve studies (83%), all of which used an automated system.^{14–20,22,24,25} Other analysis guidelines regarding IMT calculation, cardiac phase and plaque presence were less frequently reported. Three studies specified the point(s) in the cardiac cycle at which cIMT was measured,^{14,15,25} but the study by Jae *et al.* was the only one to specify acquisition at end diastole as recommended by both consensus guidelines.¹⁵ Only four studies (36%) were judged to have clearly specified the measures of central tendency used to calculate the final reported cIMT values.^{14,21,22,24} Similarly, five of twelve studies (42%) stated how plaque presence was handled.^{16,17,19,21,23} Eight of twelve studies (67%)^{14,16–19,21,24,25} measured lumen diameter as requested by the MCAB,^{13,15–18,20,23,24} but inter-adventitial diameter was never measured. Multiple studies calculated a measure of reproducibility such as intra- and inter-observer variability, however only two studies (18%) reported an intra-class correlation as recommended by the MCAB.^{15,23}

Additional reporting

Assessor training or skill was reported in half of the studies (Table 3).^{16–20,24}

Overall reporting

On average, 53% of the criteria specified in the published statements were present in the selected literature (Table 3). The highest reporting rate of the quality criterion in study methods was 10/15 (67%) and was

present in three studies.^{15,17,19} No study was scored as high in quality reporting methods. Five studies were scored as moderate,^{15,17–20} while the remaining seven scored low.^{14,16,21–25} Examining only the studies of moderate quality, the available cIMT values in SCI range from 0.46 mm to 0.74 mm (± 0.02 –0.07). In contrast, able-bodied controls range from 0.44 mm to 0.62 mm (± 0.06 –0.07).

Discussion

This review describes the current state of cIMT acquisition and analysis quality in individuals with SCI. The primary finding of this review is that the current literature reporting cIMT values among individuals with SCI was scored as low to moderate in quality reporting of the study methods.

Acquisition

A range of protocols exist regarding the acquisition of cIMT data. Within the current literature, aspects of the acquisition location including arterial side, and wall were variable (Table 3). In order for data to be pooled between studies, similarities in acquisition protocols are needed. Differences in carotid segment, wall and ultrasound angles for acquisition have all been associated with variances in cIMT value, reproducibility and magnitude.^{26,27}

Analysis

A majority of measurement systems specified in the SCI literature were automated (Table 3). This shift away from manual techniques is a positive step for the field as automated systems reduce some sources of technician reader variability.^{26,28} An area that warrants clarification, however, is the distinction between fully-automated and semi-automated measurement systems. While the majority of the current literature reported ‘automated’ systems, many may indeed be semi-automated. Semi-automated systems are preferred by the ASE over manual and fully-automated methods, but are not clearly defined in the ASE consensus statement. Further standardization of the measurement system definitions are required as these processes have been shown to differ significantly in accuracy and reproducibility.^{29,30}

Measures of central tendency

An important procedural aspect to consider when analysing cIMT is the choice of measure of central tendency. Multiple calculations of mean or maximum are needed to derive a final cIMT value. In theory, the particular measurements used should be determined by the intent of the test. Whereas a maximum measurement

would have high sensitivity, which is ideal for screening, it would have low specificity and be susceptible to false negatives. Contrarily, mean values would have higher specificity but low sensitivity.

Lumen diameter and normalized cIMT

Fundamental principles of ultrasound delineation of anatomical structures must be taken into account when defining ultrasound landmarks (i.e. the leading vs. far edges). Current cIMT literature differs on the definition of lumen diameter. For instance, Gando *et al* defines lumen diameter as the distance between the lumen-intima interface of the far wall and the media-adventitia interface of the near wall.³¹ However, lumen diameter is defined by Wikstrand *et al.* as the distance between the two leading edges of the near and far wall intima-lumen echoes.³² The lumen diameter may be used to normalize cIMT values. Normalizing cIMT theoretically reduces bias resulting from physiological differences in artery size, as lumen diameter is strongly related to IMT.²⁷ Four of the studies that were examined used lumen diameter to normalize cIMT.^{14,18,19,24} Each of these studies found that normalized cIMT did not alter the trends observed with cIMT alone. Lumen diameter thresholds are not defined by the ASE or MCAB and is an area for future advancement of the field.

The role of diastole

An aspect of cIMT analysis that is agreed upon by both the ASE and MCAB is that cIMT should be collected at end diastole. This is due to pulsatile changes in pressure causing cyclic variation in IMT.²⁷ Only one study¹⁵ specified that end-diastolic IMT was collected, while two other studies^{14,25} specified other points within the cardiac cycle. A possible explanation for poor reporting is that some measurement systems automatically extract IMT. Despite the automated extractions, authors should be aware of this concern and the acquisition timing specified.

Reporting of plaque presence

Both consensus papers agree that plaque should be reported, however, the specifics of how it should be reported are disagreed upon. The ASE recommends that plaque be traced as part of the cIMT as has been done by previous major epidemiologic studies. Contrarily, the MCAB recommends that cIMT measurements be taken in a region free of plaque. The inclusion or exclusion of atherosclerotic plaques was reported in under half of the studies. It is feasible that plaque was rarely encountered due to the small study

sample sizes. Further clarification is required regarding the detection and reporting of plaque location.

cIMT reproducibility

The MCAB recommends assessment of cIMT measurement variability through intra-class correlation coefficients (ICC). While two studies assessed variability in this way,^{15,23} five other studies reported alternate measures of reproducibility.^{14,16,17,19,25} Clarification should be provided as to the requirement for an ICC or if alternative calculations are acceptable.

Overall findings

The finding of heterogeneity between studies with regards to acquisition and analysis methods is not uncommon. Reviews of cIMT in other populations have also found that the inherent differences in acquisition and analysis procedures have limited the ability to pool data.^{6,7} Although the current reporting of cIMT methodology is poor within the available literature, this is not to say that the data collection or analysis methodology used in these studies is necessarily poor, but that the reporting of methodological detail is insufficient. If one removes the six articles that predate the publication of the consensus guidelines examined in this review,^{14–17,21,23} the overall quality reporting of study methods would not alter considerably.

Advantage of cIMT assessment in SCI population

The deterioration of vascular function, presence of inflammatory stress, and subsequent development of atherosclerosis after SCI is often asymptomatic, with individual's experiencing myocardial infarction, stroke or sudden death as their presenting symptoms.³³ Therefore, it is imperative that clinicians have practical techniques for assessing and tracking CVD risk in individuals with chronic SCI at their disposal.¹² However, usual methods for coronary artery disease assessment in the able-bodied population such as myocardial perfusion imaging, coronary CT and angiography are difficult to access (physically and systematically), involve risks (such as radiation or vascular access) and thus are not widely applied or available to the SCI population. Additionally, exercise stress testing is not always feasible in this population, as individuals with SCI may have limited upper arm function to conduct the exercise test, specifically those with tetraplegia. Pulse Wave Velocity (PWV), specifically carotid-femoral PWV (cfPWV), is a promising diagnostic test for the early detection vascular end-organ damage and has been used in the field of clinical research in the SCI population.³⁴ However, the femoral pressure

waveform may be difficult to record accurately in individuals with metabolic syndrome, central obesity, diabetes, and peripheral artery disease. Abdominal obesity, particularly in men, and large bust size in women, can make distance measurements inaccurate in cfPWV calculations.³⁵ With these issues in mind, cIMT assessment by high resolution B-mode ultrasonography may be an effective alternative. Moreover, an advantage to cIMT measurement lies in its rapidly applicable and available, non-invasive and cost-effective nature.⁹

Key considerations for cIMT assessments in SCI population

As mentioned earlier, quality cIMT methods may be challenging to implement in the spinal cord injury population when compared to the general population. This is due to the heterogeneity of SCI, which results in diverse motor, sensory and autonomic impairments and associated regional declines in lean mass and increases in intramuscular, visceral and abdominal fat mass.³⁶ In addition, for individuals with high paraplegia and tetraplegia, one can anticipate alterations in heart rate and rhythm, body temperature, trunk control and respiratory function. These impairments may combine to potentially influence the patient's ability to maintain a specific and consistent head and neck posture during cIMT acquisition. Further, for those with tetraplegia requiring anterior open reduction and internal fixation, surgical scarring and regional hardware may also influence cIMT data acquisition and interpretation. These challenges aside, cIMT is a burgeoning field whose growth is dependent on quality acquisition and analysis to ensure accurate reporting of CVD risk.

Limitations

There are several limitations of this study that require consideration prior to generalizing the research findings. One major limitation stems from publication word limits in the 12 examined studies enforced by journal editors. With this in mind, a study's methods section may have been scored as low in quality due to word limits imposed on authors by journal editors, rather than a lack of methodological rigor. Furthermore, with regards to the literature search, studies published after the search dates were not included in this review. There are other limitations that arise from the development of Table 3 that may affect its applicability. First, the guidelines used to appraise the literature were abstracted from two consensus papers which did not concur with one another on each criterion, leaving it

up to investigator interpretation as to what should be included, as specified for items 8, 9 and 11. Second, there is regional and international variation in cIMT methods and the extent of clinical implementation that may in part be due to regional variation in access to cIMT equipment and funding for routine testing. Third, the quality classifications developed by the authors was arbitrary and have not been psychometrically evaluated, although we believe the process has face validity. Fourth, the methodology stated in the published literature occasionally lacked clarity (i.e. the measures of central tendency used to calculate final cIMT value). Therefore, populating Table 3 required interpretation from the authors as to whether specific quality reporting methods were met or not. Last, six studies examined pre-date the publication of the consensus guidelines.^{14-17,21,23} However, regardless of the timing of publication, there were no remarkable differences in the quality of reporting.

In addition, the clinical importance or positive predictive value of an elevated cIMT in individuals with SCI is unclear. Large scale, prospective longitudinal studies in a representative sample of individuals with SCI are required to determine whether cIMT will predict future CVD events in individuals with SCI at similar or different rates to the general population. Furthermore, future studies should address the current gaps in terms of under-representation of women, individuals with tetraplegia and incomplete injury. Further and perhaps most importantly, studies to determine the effect of physical activity on cIMT values are encouraged to establish a physical activity recommendation specifically aimed at prevention of atherosclerotic disease in the SCI population.

Conclusions

Multiple aspects of quality reporting need to be addressed to progress the cIMT literature in SCI research: (i) Adherence to the current guidelines at a rate of greater than 80% is needed; (ii) Future refinement of cIMT reporting guidelines are needed to aid authors designing research as well as journals in selecting manuscripts for publication.

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