Special Issue Article

Global Spine Journal
2022, Vol. 12(1S) 64S–77S

DOI: 10.1177/21925682211063854
journals.sagepub.com/home/gsj
SAGE

Improving Assessment of Disease Severity and Strategies for Monitoring Progression in Degenerative Cervical Myelopathy [AO Spine RECODE-DCM Research Priority Number 4]

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Abstract

Study design: Narrative Review.

Objective: To (i) discuss why assessment and monitoring of disease progression is critical in Degenerative cervical myelopathy (DCM); (ii) outline the important features of an ideal assessment tool and (iii) discuss current and novel strategies for detecting subtle deterioration in DCM.

Methods: Literature review

Results: Degenerative cervical myelopathy is an overarching term used to describe progressive injury to the cervical spinal cord by age-related changes of the spinal axis. Based on a study by Smith et al (2020), the prevalence of DCM is approximately 2.3% and is expected to rise as the global population ages. Given the global impact of this disease, it is essential to address

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important knowledge gaps and prioritize areas for future investigation. As part of the AO Spine RECODE-DCM (Research Objectives and Common Data Elements for Degenerative Cervical Myelopathy) project, a priority setting partnership was initiated to increase research efficiency by identifying the top ten research priorities for DCM. One of the top ten priorities for future DCM research was: What assessment tools can be used to evaluate functional impairment, disability and quality of life in people with DCM? What instruments, tools or methods can be used or developed to monitor people with DCM for disease progression or improvement either before or after surgical treatment?

Conclusions: With the increasing prevalence of DCM, effective surveillance of this population will require both the implementation of a monitoring framework as well as the development of new assessment tools.

Keywords
degenerative cervical myelopathy, cervical spondylotic myelopathy, ossification of the posterior longitudinal ligament, clinician-reported outcome measures, patient-reported outcome measures, monitoring, outcome assessment

Introduction

Degenerative cervical myelopathy (DCM) is an overarching term used to describe progressive injury to the cervical spinal cord by age-related changes of the spinal axis, including disc prolapse, osteophyte formation and hypertrophy or ossification of supporting ligaments.[1] Congenital pathologies may also predispose individuals to DCM, including Klippel-Feil Syndrome or Congenital Canal Stenosis.[2,3] Based on a study by Smith et al (2020), the prevalence of DCM is approximately 2.3% and is expected to rise as the global population ages.[4] DCM can result in significant neurological and functional impairment, disability and reduced quality of life. In fact, a recent study compared Short Form-36 (SF-36) scores among individuals living with chronic disease and identified DCM as one of the worse conditions with respect to quality of life.[5] Given the global impact of this disease, it is essential to address important knowledge gaps and prioritize areas for future investigation.

As part of the AO Spine RECODE-DCM (Research Objectives and Common Data Elements for Degenerative Cervical Myelopathy) project, a priority setting partnership was initiated to increase research efficiency by identifying the top ten research priorities for DCM.[6] This process was facilitated by the James Lind Alliance, a non-profit organization that ensures that proposed research priorities reflect the perspectives of health care professionals, patients and caregivers. One of the top ten priorities for future DCM research was:

What assessment tools can be used to evaluate functional impairment, disability and quality of life in people with DCM? What instruments, tools or methods can be used or developed to monitor people with DCM for disease progression or improvement either before or after surgical treatment?

Clinical assessments tools provide a rating or a score in order to capture an aspect of a patient's health status.[7,8] These assessments exist in a wide range of forms and include investigations such as serological testing, electrophysiology and imaging. The focus of this research priority is on tools that can summarize "life impact"; specifically, how a disease impairs function, leads to disability and influences quality of life.[8]

The objectives of this review are to (i) discuss why assessment and monitoring of disease progression is critical in DCM; (ii) outline the important features of an ideal assessment tool and (iii) discuss current and novel strategies for detecting subtle deterioration in DCM.

Why Is Assessment and Monitoring Required in Degenerative Cervical Myelopathy?

Clinical assessments are valuable in both a clinical and research setting. These tools can objectively assess disease severity, monitor neurological progression and evaluate the effectiveness of treatments.[9] Furthermore, according to a study by Davies et al (2016), many important research questions are difficult to address due to the heterogeneity of outcome measures used across studies.[10] The lack of consistency in assessment has prevented inter-study comparisons, the development of clinical practice guidelines and the formation of recommendations surrounding the optimal management of DCM.

The management of DCM varies based on disease severity. According to a clinical practice guideline, patients with moderate to severe myelopathy should undergo surgery to prevent further deterioration and improve existing neurological deficits.[11] Decision-making, however, is less straight forward in patients with mild myelopathy as well as in nonmyelopathic patients with image-evidence of spinal cord compression. In patients with mild myelopathy, the guidelines suggest offering surgical intervention or a supervised trial of structured rehabilitation; if nonoperative management is initially pursued, surgery is recommended if there is neurological deterioration and is suggested if a patient fails to improve clinically.[11] Nonmyelopathic patients with evidence of spinal cord compression on imaging should not undergo prophylactic surgery, but rather be counselled on the potential risks of progression, educated on relevant symptoms of myelopathy and followed appropriately.[11] This guideline, however, did not provide a framework for how to follow these patients and what tools can be used to detect onset of myelopathy.

Effective monitoring is critical in these patient populations as individuals may remain stable for years, exhibit slow progression or deteriorate rapidly.[12] According to Tetreault et al, disease severity and duration of symptoms are important predictors of surgical outcomes.[13-15] As such, clinical assessments that can be easily adopted by the primary care and allied health community and can detect subtle neurological deterioration may improve timely management of DCM.[16]

Assessments that can identify meaningful changes in clinical status are also critical for DCM research, especially for the translation of adjuvant therapies. Inherent variation in assessment poses several challenges in clinical trials, including a need for increased sample size and the potential to mask positive effects.[17,18] For example, the Cervical Spondylotic Myelopathy Protect Trial required a total of 400 patients in order to detect differences in the modified Japanese Orthopedic Association (mJOA) score between a riluzole and placebo group in individuals undergoing surgical decompression for DCM.[19] Unfortunately, no significant differences in mJOA scores were identified between the study arms. The investigators speculated that a positive treatment effect was masked by the larger treatment effect delivered by surgery and the lack of discrimination offered by the mJOA.

What are the features of an ideal assessment tool?

The quality of a clinical assessment is discussed in terms of its psychometric properties or clinometrics.[20] Although there is inconsistency in the terminology used to categorize these properties, the 3 most critical domains are validity, reliability and responsiveness to change.[21,22]

1. Validity, defined as whether a particular instrument measures what it was developed to measure. There are three main forms of validity: content, construct and criterion. Content validity is an evaluation of the extent to which an assessment tool represents all facets of a given construct. In the case of DCM, an instrument may demonstrate content validity if it incorporates items that cover all manifestations of the disease, including upper and lower extremity motor and sensory impairment, bladder and bowel dysfunction and neck and shoulder pain. Construct validity is a measure of how well a tool correlates with an operationalized construct and consists of convergent (the degree to which 2 constructs are related that theoretically should be related) and divergent (the degree to which 2 constructs are unrelated that theoretically should be unrelated) validity. Finally, criterion validity is an assessment of how well an instrument predicts a known construct.
2. Reliability, defined as the degree to which an assessment tool consistently measures a particular construct. An effective tool must demonstrate both inter-rater (agreement between two or more raters) and intra-rater (agreement between two ratings made by the same individual on the same patient) reliability. A reliable tool in DCM can effectively report any change in disease status even if the patient is assessed by two different examiners.
3. Responsiveness to change, defined as the ability of an instrument to detect change over time in a particular construct. A tool that can detect subtle changes in clinical status would be invaluable in a DCM setting as disease progression may be an important indicator that a patient should undergo surgical intervention.

The COSMIN (Consensus-based Standards for the selection of health Measurement Instruments, [www.cosmin.nl]) initiative defines a fourth important characteristic of a measurement instrument: interpretability.[20] Interpretability refers to what a score or change in score means in the context of the disease. DCM can have a diverse impact on an individual's function, mental health and independence in activities of daily living.[23] Given the nature of this disease, assessment tools are often multi-dimensional which may affect their interpretability. Specifically, the magnitude of change in one dimension may not be equivalent to the same change in another dimension.

While these measurement properties represent key principals of assessment, other characteristics must be considered before a tool can be adopted in a clinical setting. Specifically, is the instrument inexpensive, accessible and easy to administer? Can it be applied with little or no training?[24] These features of an assessment tool will be increasingly important to consider when developing an outcome measure for DCM. Although the epidemiology of DCM is currently poorly characterized, it is likely that the majority of cases are mild and/or asymptomatic.[4,25] Cost-effective, long-term surveillance for 1 to 2% of the population will therefore need to rely on patients and non-specialists, including primary care practitioners and allied health professionals.

What Type of Assessment Tools Are Available?

Disease course and treatment benefit can be evaluated using outcome assessment tools that directly, or indirectly, measure a patient's level of impairment, quality of life or survival. In general, assessment tools can be divided into 2 categories: those applied by a patient (Patient-Reported Outcome Measures, PROMs) and those performed by a health care professional (Clinician-Reported Outcome Measures, ClinROMs).

Patient-Reported Outcome Measures

Patient-reported outcome measures are standardized tools used to evaluate an individual's perception of his or her level of impairment, disability and quality of life.[26] PROMs are defined as "any report of the status of a patient's health condition that comes directly from the patient, without interpretation by a clinician or anyone else." (26) These tools aim to capture information on outcomes that patients care about, such as symptom burden, personal health care experience, satisfaction

and quality of life.[26,27] PROMs can also garner data on access to care, treatment adherence and safety of interventions. Patients' perspectives provide a more holistic view on the impact of a medical condition or intervention on physical, emotional and social well-being.[27] In 2000, there was an increase in the focus of PROMs when the Institute of Medicine acknowledged patient-centeredness as one of the 6 aims of health care delivery.[28] In fact, clinical trials are increasingly adopting PROMs in their study designs in order to provide a more comprehensive assessment of treatment outcomes.[29]

Unfortunately, there is a lack of consensus on what instruments are best suited to assess a patient's perspectives. There are two categories of PROMs: generic and disease-specific.[30] Generic PROMs consist of broad domains that can be applied to a wide range of healthy and chronic disease populations and include the SF-36 and EQ-5D. In contrast, disease-specific PROMs have greater face validity as they assess more distinct aspects of a disease.

One of the challenges in developing a PROM is that there may be significant variability in how an individual interprets the wording of a question. To overcome these challenges, platforms such as PROMIS (Patient-Reported Outcomes Measurements Information System) provide researchers with standardized questions for a wide range of health domains that have been extensively tested.[30,31] This system offers item banks with sets of questions that can be combined into a questionnaire that is relevant to a particular disease.

There are further limitations to PROMs. Responses by patients will invariably depend on their current physical and psychological state and may not reflect their experiences over time.[32] Furthermore, some individuals may not accurately report their perspectives due to fear that their responses may negatively impact their care (32). PROMs can also be time consuming and significantly influenced by patient demographics, including culture and language.[33] Regardless of these limitations, patient perspectives are invaluable in guiding treatment decisions and detecting subtle changes in disease status. Improving these outcomes is critical for confirming the effect of various treatment strategies.

In DCM, generic PROMs have been adapted to assess health-related quality of life and the impact of disease on activities of daily living. In contrast, there is a paucity of disease-specific PROMs that may help guide management. PROMs can be used in a DCM setting as a surveillance tool to help detect changes in a patient's symptoms that may influence frequency of health care visits and recommended treatments. Appropriate development of disease-specific PROMs must incorporate the opinions of patient focus groups and relevant health care practitioners in order to capture the domains that are most important to the patient.

Clinician-Reported Outcome Measures

ClinROMs are instruments used by observers with appropriate professional training.[34] These tools are useful when clinical judgement is necessary to make an assessment or when a patient is unable to effectively evaluate his or her symptoms or disease status. While a patient's perspective is essential for understanding symptom burden and treatment effect, many components of a disease require evaluation by trained health care professionals. ClinROMs must encompass clinically meaningful aspects of a disease and must be consistent across studies.

ClinROMs can consist of multiple components that require clinical judgement. Although biomarkers, such as imaging or laboratory findings, can be used by clinicians to form opinions, they cannot be the sole decision-maker when it comes to ClinROMs (34). For example, a patient may have evidence of canal stenosis and cord compression on an MRI (i.e. an imaging biomarker), but without symptoms or signs of myelopathy, a clinician cannot diagnose DCM. There are different types of ClinROMs: readings, ratings and global assessments.[34] Readings refer to clearly defined results that can be observed and reported in a dichotomous manner (e.g. yes vs no; presence vs absence).[34] Ratings are categorical or continuous scales that have at least 3 possible levels; results from these scoring systems can ultimately be dichotomized (e.g. success vs failure). Finally, clinician global assessments are based on a clinician's judgement of patients' "total health status or an aspect of their health status for which the variables evaluated are not consistently defined or are undefined."

A systematic approach is required to develop the framework of a ClinROM. This framework must incorporate multiple sources of evidence, including information from literature reviews, patient interviews and opinions from expert clinicians.[35] A ClinROM will likely undergo multiple cycles of development, review and revision before a final draft is produced. Each component of a ClinROM must be accurately defined as there are likely to be discrepancies among clinicians with respect to quantification and qualification of symptoms and disease states.[35] Finally, the psychometric properties of a ClinROM must be rigorously assessed, including validity, reliability and responsiveness to change.

What assessment tools are used to evaluate patients with DCM?

Several tools have been cited in the literature that evaluate different components of DCM (Figure 1).[10] Although these tools have frequently been used in research studies, it is unclear which assessment measures are used routinely in clinical practice. It is critical to develop a standardized system for evaluating severity and monitoring disease progression in DCM. As part of the AO Spine RECODE-DCM project, a consensus process is underway to define which of the currently available tools should be used in research and in clinical practice.[6] This section aims to summarize the strengths and weaknesses of common instruments used to assess important outcomes in patients with DCM.[10]

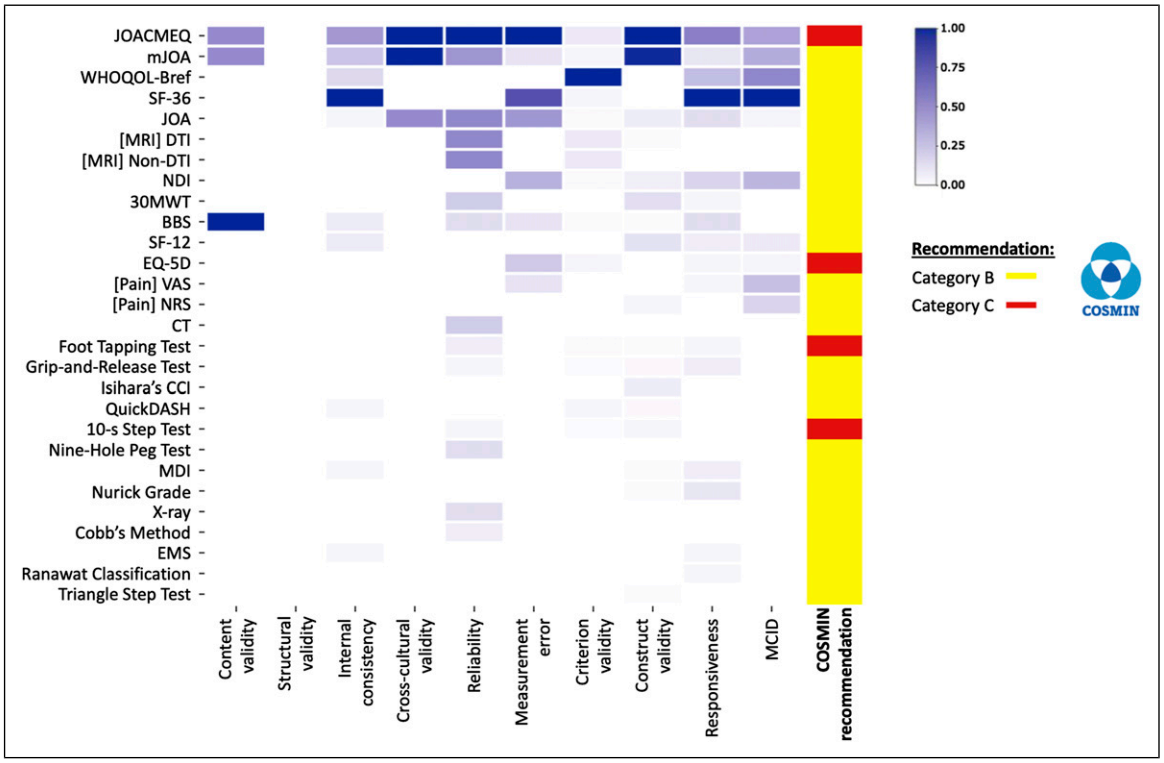

Figure 1. Evaluation of the Psychometric Properties of PROMs and ClinROs in DCM. The number of studies assessing each tool and psychometric property was normalized to the maximum number of studies in the matrix. No tools were recommended for use (Category A); 24 were categorized as potential candidates for use, subject to further quality assessment (Category B); and 4 were not recommended for use (Category C).

Patient-Reported Outcome Measures

Neck Disability Index. The Neck Disability Index (NDI) was established in 1991 and was the first instrument designed to evaluate self-reported disability in individuals with neck pain.[36] It is a 10-item questionnaire that assesses pain intensity, presence of headaches and the impact of neck symptoms on recreation, self-care, lifting, reading, concentration, work, driving and sleeping. Each item is scored on a 0 to 5-point scale.[37] Scores from each subscale are summated to give a score out of 50. Several studies have evaluated the psychometric properties of the NDI in a variety of populations, including neck pain, cervical radiculopathy and whiplash associated disorder.[37,38] The NDI has high test-rest reliability (.90 to .93), is internally consistent (Cronbach's alpha from .74 to .93) and consists of a single dimension, namely, physical disability.[37] It demonstrates convergent validity as it is strongly correlated with several instruments that aim to measure the same construct. The minimum clinically important difference (MCID) of the NDI ranges from 3.5 to 10 depending on which patient population is being studied.[38,39] A study by Carreon et al (2010) reported the MCID of the NDI as 7.5 in patients undergoing cervical fusion for degenerative spine conditions.[40] Finally, effect sizes, standardized response means and responsiveness ratios range from .8 to 1.82.[37] The NDI has been effectively translated into 6 languages. The major limitation of the NDI for DCM is that is evaluates the functional impact of neck pain but does not measure the effects of lower or upper extremity symptoms or gait impairment on activities of daily living.

Quick Disabilities of the Arm, Shoulder and Hand

The Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) is a self-administered questionnaire that measures physical function and symptoms related to upper limb musculoskeletal disorders.[41] The QuickDASH consists of 3 modules: disability and symptoms, work, and sports and performing arts.[42] The disability and symptom modules are comprised of 11 items that focus on activities of daily living; recreational, social and work activities; arm, shoulder and hand sensation and pain; and sleeping. Items are score from 1 (no disability) to 5 (unable), summed and then normalized from 0 to 100. The higher the score, the greater the disability. The QuickDASH has been validated for use in the DCM population, is able to discriminate among mild, moderate and severe disease and demonstrates concurrent validity with the GRASSP-M (Graded Redefined Assessment of Strength, Sensibility and Prehension, Myelopathy Version).[43] This tool has been recommended by Kalsi-Ryan et al (2019) to assess disability in patients with DCM.[43]

Short Form-36 Version 2

The SF-36 is a tool that evaluates patient-reported health status and quality of life.[44,45] The SF-36 consists of 8 subscales (vitality, physical functioning, bodily pain, general health, role-physical, social functioning, role-emotional and mental health) that can be combined to form a Physical Component Score (PCS) and a Mental Component Score (MCS).[44] The SF-36 is internally consistent (Cronbach's alpha of .92 for PCS and MCS), has moderate responsiveness to change, and demonstrates high test-retest reliability (>.75 for all subscales except for social functioning and role-physical and role-emotional).[46,47] This scale is often used to validate other assessment tools used to evaluate patients with DCM.[9] It has demonstrated convergent, divergent and construct validity. The MCID of the SF36v2 PCS and MCS is 4 points.[48]

Visual Analogue Scale for Pain

The Visual Analogue Scale (VAS) has been used in a broad range of settings to measure the degree of symptoms, such as pain.[49] Patients are asked to rate the intensity of their pain by drawing a mark along a line from 0 to 100. The distance is then measured between the start of the line on the left and the patient's mark. The VAS is a simple and efficient way of assessing pain that does not require any equipment or formal training. It is more sensitive to small changes in pain than other descriptive scales, demonstrates validity against other pain scales and can be easily translated into different languages.[49,50] MacDowall et al (2018) evaluated the repeatability and the MCID of the VAS-neck pain and VAS-arm pain instruments in patients with cervical radiculopathy secondary to degenerative spine disease.[51] Based on their results, the repeatability for the VAS-neck and VAS-arm was 8.1 mm and 10.4 mm, respectively. The MCID for the VAS-neck ranged from 4.6 to 21.4 mm based on methodology and from 1.1 to 29.1 mm for the VAS-arm. Limitations of the VAS include (i) assessment is highly subjective and may be influenced by the environment, time of day or patient demographics; (ii) there is an inability to discriminate between a range of numbers on a 100-point scale and (iii) it may be conceptually complex for certain populations.[50,51]

Clinician-Reported Outcome Measures

(Modified) Japanese Orthopedic Association Score. The Japanese Orthopedic Association (JOA) score was originally developed in 1975 in order to assess motor function of the upper and lower extremities, sensory function of the arms, trunk and legs and autonomic function of the bladder in patients with DCM.[52] It is a self-administered, disease-specific instrument that significantly improved the ability to evaluate impairment and disability in DCM. The JOA was later revised in 1994; this revision refined the scoring for sensory and autonomic function and included manual muscle testing of the elbow and shoulder.[53] In terms of psychometric properties, the 1975 JOA demonstrated (i) acceptable internal consistency for research purposes but not for clinical purposes[54]; (ii) low sensitivity to change (overall .21; .04 for sphincter function to .35 for hand function)[54]; (iii) a MCID of at least 2 points[55]; (iv) unknown reliability; and (v) convergent and divergent validity based on correlations with other scales.[52] Based on a study by Yonenobu et al (2001), the intra-rater agreement for the revised version of the JOA varied from 57.1% (lower limb sensory function) to 82.9% (elbow and shoulder motor function), while the inter-rater agreement ranged from 62.3% (lower limb motor function) to 82.3% (elbow and shoulder motor function).[53]

The JOA was later modified to the mJOA to improve its compatibility with Western populations.[56-58] The mJOA is an 18-point DCM-specific, clinician-administered tool that separately addresses motor function of the upper and lower extremities, sensory function of the upper extremities and sphincter function.[52] According to a study by Kopjar et al (2014), the mJOA consists of two key dimensions: micturition and motor and sensory function of the upper and lower extremities.[59] It has moderate internal consistency, demonstrates both convergent and divergent validity and is responsive to change.[59] The total mJOA score and its subscales have good inter-rater reliability (ICC>.75) with the exception of upper extremity sensory function.[60] Although the mJOA is an ordinal scale, it is likely not linear in terms of impact on quality of life and need for surgical intervention. For example, a one-point change in an individual's mJOA score could either reflect the difference between buttoning a shirt with mild vs great difficulty or the difference between being able to walk with a walker and not being able to walk at all. The mJOA also exhibits a ceiling effect, meaning it is difficult to detect subtle improvements in patients with milder disease.

Based on a study by Tetreault et al (2017), disease severity can be classified as mild, moderate or severe based on the mJOA score.[61] Mild myelopathy is defined as a mJOA from 15 to 17, moderate as a mJOA from 12 to 14 and severe as a mJOA from 0 to 11. The MCID for the mJOA score varies based on preoperative severity.[62] Specifically, the MCID for patients with mild myelopathy is 1, for moderate is 2 and for severe is 3. Finally, the mJOA score can be translated from English to Italian, Portuguese and Dutch with retained validity.[63-65]

Gait Assessment

Gait disturbance is considered to be one of the earliest manifestations of DCM and is therefore essential to assess in milder disease stages. The gait of a myelopathic patient is often described as broad-based and unstable and is likely due to upper motor neuron and proprioceptive dysfunction.

Gait can be assessed by performance-based outcome measures, the simplest of which is the time 30m walk test (30MWT).[66] Based on a study by Bohm et al (2017), the

30MWT correlates with disease severity, demonstrates convergent and divergent validity and exhibits high test-retest reliability.[67] This tool is simple to use in a clinical setting and can be employed with minimal equipment and training. Overall, the 30MWT is not responsive to change which can limit its use in patients with mild myelopathy (67). Qualitatively, however, the 30MWT can help distinguish between individuals who can perform the test and those who are unable to ambulate due to severe myelopathy. Furthermore, this test only measures gait velocity and no other parameters that may be affected by DCM at earlier stages of the disease.

Equipment such as 3-dimensional motion capture, specialized walkways and pressure sensors can be used to measure various kinematic and kinetic gait parameters.[68] Several studies have compared spatio-temporal gait patterns between patients with DCM and healthy, age-matched controls. Based on their findings, patients with DCM have decreased gait velocity, a shortened stride length, increased double support time, a wider step width and slower cadence.[69-73] Furthermore, as the severity of myelopathy increases, velocity and step length decrease, while step width and angle increase.[74,75] Finally, patients with DCM exhibit a decrease in several kinematic and kinetic parameters, including knee flexion during swing, peak ankle plantarflexion, anteroposterior ground reaction force (GRF) at toe-off, power absorption at the knee in loading response and terminal stance, and power generation at the ankle.[69,71,72,76,77] Following decompressive surgery, individuals may exhibit improvement in several gait parameters, including increased cadence and velocity and reduced double support time. These postoperative results suggest that these assessments are responsive to change. The psychometric properties of gait analysis in DCM have not been fully investigated. In a study by Mcdermott et al (2010), the test-retest reliability was good to excellent for spatio-temporal parameters, total range of motion and kinematic factors such as vertical and anteroposterior GRF.[78] Important limitations to formal gait analysis include (i) the requirement for specialist equipment and training and (ii) the ability of other common degenerative pathologies (e.g. degenerative joint disease, frailty) to alter gait parameters.

The gait deviation index (GDI) was originally developed by Schwartz et al (2008) to evaluate gait abnormalities in patients with cerebral palsy.[79] It is a composite score that consists of 15 gait parameters, including pelvic tilt, obliquity and rotation; right and left hip flexion, adduction and rotation; right and left knee flexion; ankle plantarflexion; and foot progression. In a study by Mar et al (2020), GDI scores were compared between health controls and patients with DCM, adult degenerative scoliosis, degenerative lumbar spondylolisthesis and lumbar degeneration. Based on their results, GDI scores were significantly reduced in myelopathic patients but were not as low as in patients with lumbar degeneration.

Gait variability is defined as the fluctuation of gait parameters between steps.[80] The enhanced gait variability index (eGVI) consists of step length, step time, stance time, single-stance time and stride velocity.[81] Based on a study by Kalsi-Ryan et al (2020), eGVI increases significantly from healthy controls to patients with mild, moderate and severe myelopathy.[82] This finding is relevant as gait deficits are typically not detected in patients with mild myelopathy during routine clinical exam or assessment of gait velocity. This eGVI may be useful for detecting small changes in gait function, identifying earlier disease states and monitoring disease progression.

Graded Redefined Assessment of Strength, Sensibility and Prehension, Myelopathy Version. The GRASSP was originally developed to assess upper limb function in patients with traumatic tetraplegia.[83] It was later modified to increase its applicability in patients with DCM. The GRASSP-M evaluates sensation on the palmar aspect of the hand, manual dexterity through a single prehension task and the strength of cervical myotomes.[84] It can be administered by any trained clinician within 10 to 15 minutes. The GRASSP-M can objectively quantify hand impairment and provide an accurate assessment of the functional deficits in patients with DCM. This information allows for earlier disease detection, improved patient monitoring and treatment planning.[84] Based on a study by Kalsi-Ryan et al (2020), the GRASSP-M is a valid and reliable tool for quantifying impairment of fine motor skills in a clinical setting.[84] As a result, this tool can be used by clinicians to assess and monitor patients with DCM, regardless of whether they are candidates for surgery.

Grip Dynamometer

Patients with DCM may experience weakness of the muscles supplied by the motor nerve that is compressed in the cervical spine. Compression of motor neurons may present as atrophy of muscles, fasciculations or changes in tone or reflexes. The intrinsic muscles of the hands are commonly affected in DCM, resulting in reduced grip strength. The grip dynamometer provides an accurate assessment of hand strength that can help quantify hand disability.[42] Several dynamometers are available that have demonstrated reliability.[85] Unfortunately, these instruments have not been validated in a DCM population. There are also computerized systems that evaluate isometric pinch and grip strength and provide further information on the motor function of the hand.[86] These tools have been used in other conditions such as rheumatoid arthritis, stroke and brachial plexus injury.[87-89] Certain measurements include maximum grip strength, sustained grip strength (force exerted over the final 3 seconds of a 5 second test), three-jaw pinch strength (index and middle finger on one side and thumb on the other side) and maximum key pinch (thumb on one side and the lateral side of the index finger on the other side while making a fist).[86] The grip dynamometer and computerized grip strength systems are easy to use and provide objective data on hand function.

Other Assessments of Hand Function

Patients with DCM often experience changes in hand dexterity. Specifically, they report difficulties manipulating small objects such as buttons and screws, changes in their hand writing and an increase in hand clumsiness. Characteristic examination findings include motor weakness in the finger extensors and abductors, finger spasticity, inability to grip and quickly release objects and two-point discrimination and proprioception deficits.[90] Hand dysfunction seen in DCM is driven by both injury to the corticospinal tracts and the dorsal columns. According to a study by Smith et al (2019), complaints of reduced hand dexterity are likely due to increased stretch reflexes and worsening proprioceptive function.[91] Based on their results, patients with DCM exhibited hyperreflexia (greater peak electromyography of the flexor digitorum superficialis following movement of the metacarpophalangeal (MCP) joint from maximum flexion to extension) and reduced proprioception (greater angle at which motion of the MCP joint was detected) but similar strength (strength of the MCP during flexion and extension) to controls.[91]

A novel instrument was developed by Omori et al (2018) that assessed an individual's ability to reach for an object, grasp it between his or her right index finger and thumb, lift it to a target marker and hold in there for 3 seconds.[92] This sequence was repeated with objects with 3 different surface materials: sand paper, suede and silk. Based on their results, patients with DCM had (i) curved trajectories and higher variability of movement; (ii) significantly greater grip aperture during reach to grasp movements; and (iii) inappropriate modulation of grip force with different materials.[92] This simple tool effectively assesses different components of hand dysfunction in DCM, including weakness of intrinsic hand muscles, proprioceptive deficits, sensory impairment and pyramidal tract damage. Several other tools have also been developed to assess various components of hand function.

What Does the Future Look Like?

Currently, there is no standardized system to evaluate patients with DCM at different stages of their condition.[10,93,94] The AO Spine RECODE-DCM project has identified core aspects of the disease that should be measured (i.e. Core Outcome Set) when evaluating and monitoring patients with DCM: neuromuscular function, life impact and pain.[6] This project is ongoing and aims to identify the most appropriate tools to measure these outcomes (i.e. Core Measurement Set).

Although standardization of clinical assessment is likely to have immediate benefits, there are limitations to the measurement tools currently used to evaluate individuals with DCM.[95,96] A recent systematic review determined the psychometric properties of the PROMs and ClinROMs available in DCM using the COSMIN guidelines.[97] The quality of 28 tools assessing 7395 global patients was evaluated using modified GRADE criteria. Unfortunately, none of the 28 outcome measures were recommended for use in a clinical setting. Instead, the majority of tools (24/28) were categorized as "potential" candidates that required further research.[97] As illustrated by Figure 1, these ratings were, in part, due to the absence of studies investigating structural validity (a key aspect of construct validity) as well as the methodological limitations of the studies that assessed other psychometric properties. While an absence of high-quality evidence is not an indication that a tool is inadequate, these knowledge gaps are concerning and must be addressed. Furthermore, given the increasing number of outcome measures available and the lack of uniformity within the field, new and improved tools will likely be required.[10,42,97] The robust development of such tools will take time.

Introducing effective surveillance is not simply about new measurement instruments but also about developing an interdisciplinary framework to facilitate adoption. In DCM, surveillance systems could be implemented to monitor disease progression, dictate when a patient should present to his or her primary care practitioner and identify individuals who should be referred to spinal surgery. The following conditions are seemingly necessary in order to provide an effective surveillance system for DCM. The important components of an effective surveillance system are also illustrated in Figure 2 and Figure 3.

1. Increase awareness of DCM among primary care practitioners and allied health professionals. Ideally, individuals with DCM are diagnosed with this condition before referral to a neurologist or spinal surgeon. Surveillance systems would not be possible unless first line practitioners are educated in the subtle findings of DCM and are able to assess outcomes in a standardized fashion using ClinROMs. Another article in this focus issue addresses the importance of raising awareness, developing triage or screening tools and establishing referral pathways for patients with DCM.
2. Motivate patients to partake in their care. Clinicians cannot possibly know how patients feel on a daily basis or how symptoms may impact their quality of life. An important component of a surveillance system for DCM could be patients reporting changes in their symptoms using PROMs via online questionnaires. Any clinically meaningful changes in the scores of these PROMs should flag a patient to present to his or her primary care practitioner for further evaluation.
3. Develop a streamlined and efficient referral pathway for patients with varying severities of DCM.[98] Several countries have implemented standardized cancer referral systems to reduce waiting times, ensure accurate and efficient diagnoses and optimize treatment outcomes.[99] There are no established referral pathways for DCM which introduces challenges such as long wait

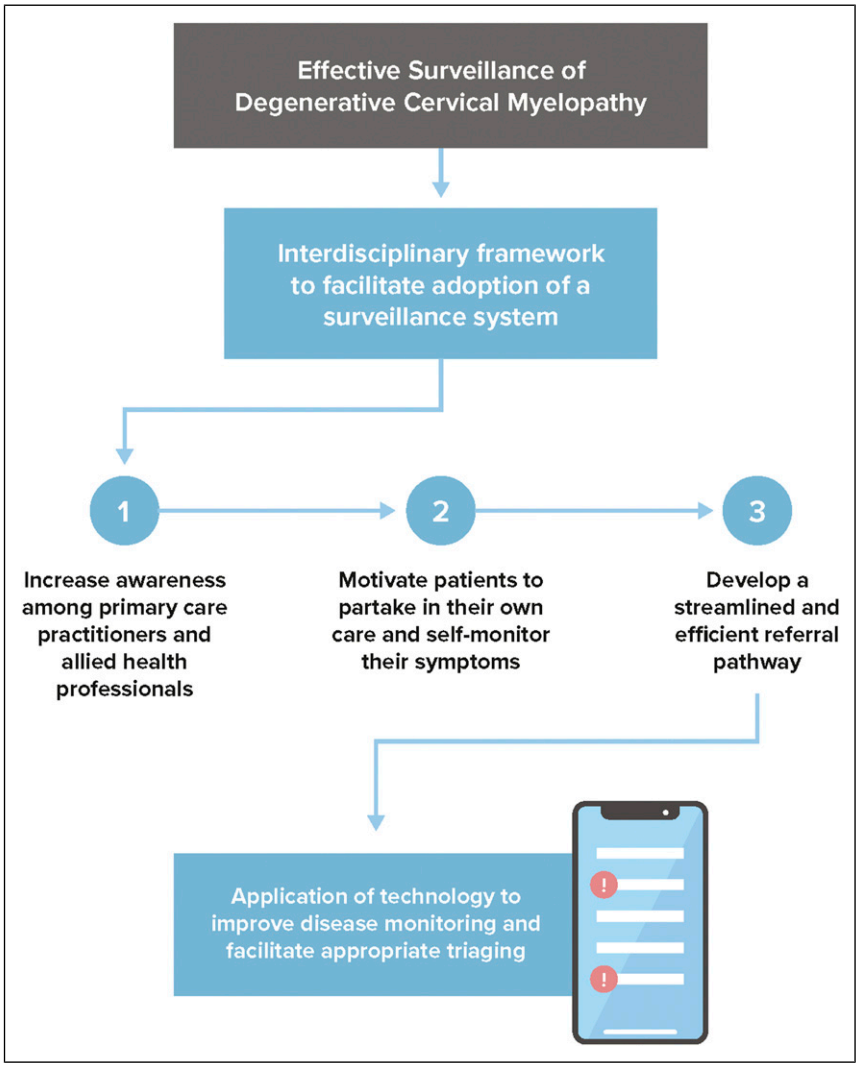

Figure 2. The important components of an effective surveillance system.

times, rejections of referrals and inappropriate triaging. Standardized care pathways are needed to enable prompt care, accurate triaging and referral to the appropriate specialist. For example, if a patient has evidence of disease progression, timely assessment by a spinal surgeon is a priority. Development of these care pathways is likely to require electronic platforms that can cost-effectively facilitate assessment and appropriate triage between community and hospital settings.

Technology has the potential to improve objective assessment of patients with DCM. Smart phone devices have been increasingly used to continuously monitor an individual's health status.[100,101] These devices have a number of embedded sensors, including an image sensor, a global positioning system sensor, an accelerometer, a gyroscope, a magnetometer, an ambient light sensor and a microphone.[102] These sensors, in combination with various applications, have been used to monitor cardiovascular activity; eye, skin and respiratory health; daily activity and falls; sleep; and cognitive function.[100,103] Furthermore, smart phone devices can be attached to other equipment such as ultrasound and fundoscope, allowing for bedside assessment of internal processes.

Disease monitoring through smartphone technology has gained increasing popularity in a variety of neurological conditions, especially Parkinson's Disease. Applications have been developed that assess several components of Parkinson's Disease, including voice, posture, gait, finger tapping, memory and response time. These applications are not only valuable to help diagnose Parkinson's Disease, but can also be used to monitor disease progression as well as assess response to medication.[104] Smartphone devices have the capacity to evaluate gait variability which may allow for a more cost-effective way to quantify changes in gait patterns and rate of falls.[105] Smartphones can also be used to determine a patient's lifespace, defined as the geographic area in which a person

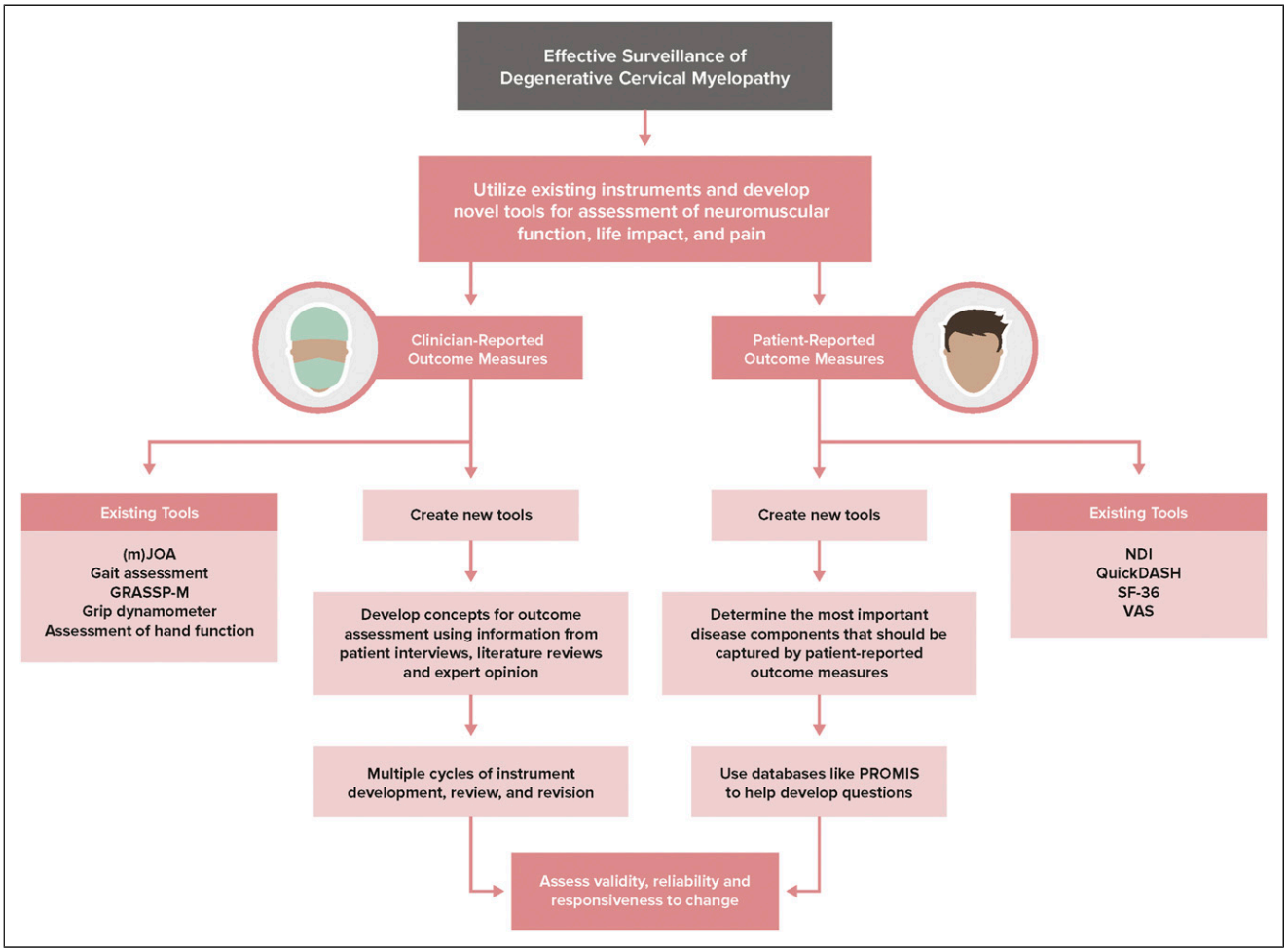

Figure 3. The need to implement existing tools and develop new clinician and patient-reported outcome measures.

lives and conducts his or her activities. A reduced lifespace may indicate worsening health, mobility or overall well-being. As such, this too, may be helpful to determine the impact of a disease on a patient's quality of life and activities of daily living.

The COVID-19 pandemic has resulted in an accelerated adoption of telemedicine approaches to clinical care, including spine surgery.[106-108] There is likely to be both an increase in appetite and acceptance for technology as a form of remote monitoring.

Conclusions

With the increasing prevalence of DCM, it is necessary to address important knowledge gaps and prioritize areas for future investigation. One of the research priorities that emerged from the AO Spine RECODE-DCM project was to improve the tools used to monitor disease progression and treatment improvement in individuals with DCM. Effective surveillance of this population will require both the implementation of a monitoring framework as well as the development of new assessment tools. While this article has contextualized the rationale for this research priority, there still is significant work that needs to be done to address this knowledge gap.

Acknowledgments

Further details on this priority, including how it was prioritized, why it was prioritized, and on-going research activity can be found at aospine.org/recode/assessment-and-monitoring

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The research priorities were organized and funded by AO Spine through the AO Spine Knowledge Forum Spinal Cord Injury, a focused group of international Spinal Cord Injury experts. AO Spine is a clinical

division of the AO Foundation, which is an independent medically guided not-for-profit organization. Study support was provided directly through the AO Spine Research Department.

MRNK is supported by the National Institute for Health Research (NIHR) Brain Injury MedTech Co-operative and BMD a NIHR Clinical Doctoral Research Fellowship. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health and Social Care.

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