MyeloPath

SMARTPHONE-BASED QUANTITATIVE ASSESSMENT *of the* SEVERITY *of* DEGENERATIVE CERVICAL MYELOPATHY

Jetan Badhiwala, MD (Specialist), #1004670457
Rabiya Noori, BSc (Programmer), #999109370
Bei Cong (Chung) Zheng, BASc (Programmer), #1000634913

Word Count: 2,499

BACKGROUND

Degenerative cervical myelopathy (DCM) is the most common cause of spinal cord injury.[1] This disorder develops when arthritis (i.e., age-related 'wear and tear' to the bones, ligaments, and discs) of the cervical spine (i.e., neck) causes compression of, and slow progressive injury to, the spinal cord, resulting in functional disability (Figure 1).[2,3] Neurological impairment secondary to DCM manifests typically as impaired gait (i.e., difficulty walking), poor balance, and loss of hand dexterity; other symptoms may include numbness of the limbs, neck or upper limb pain, and in later stages of the disease, progressive weakness and loss of voluntary control of urination and/or defecation.[4-6] In many respects, DCM can be likened to arthritis of the knee or hip; however, whereas the latter predominantly produce pain, DCM can also cause permanent paralysis. The topic of DCM has become a key public health priority in the face of a global aging population.[7]

RATIONALE

The only proven effective treatment for DCM is surgical decompression, which has been shown to halt progression of neurological deficits and improve function, disability, and quality of life.[8,9] However, surgery carries material risks, and not all patients with DCM require surgery, particularly if symptoms are absent or very mild; here, the potential risks may outweigh the benefits.[10,11] Surgical decision-making therefore relies on being able to detect subtle changes in a patient's neurological function. The problem is that current standardized methods and scales used to evaluate the severity of DCM have several important limitations. First, most DCM-specific outcome measures lack objectivity and instead rely on subjective patient self-report, either in response to a questionnaire or an interview. Second, although available scales can capture large changes (i.e., improvement or worsening) in a patient's neurological condition, they are not sensitive enough to detect small differences that may, nonetheless, be important. To illustrate, the modified Japanese Orthopaedic Association (mJOA) scale, which is considered the 'gold standard' for grading DCM, is detailed in Table 1.[12] The mJOA scale scores patients' functional abilities on an 18-point scale in the subdomains of upper limb motor function (5 points), lower limb motor function (7 points), upper limb sensation (3 points), and sphincter (urination and defecation) function (3 points), with higher scores indicating less severe impairment.[13] Major criticisms of the mJOA scale are that it is subjective and evaluator-dependent, hence lacking in reliability and reproducibility.[14,15] Further, the mJOA scale lacks responsiveness and demonstrates a strong ceiling effect; that is to say that on many occasions, there may be zero change in the mJOA score, despite a patient reporting meaningful improvement or deterioration in their DCM symptoms.[10] Tools do exist that may objectively quantify specific facets of neurological function and that can be applied to patients with DCM, namely the GAITRite for walking[16] and GRASSP for hand sensation, strength, and coordination.[17] However, these are cumbersome and time-consuming to perform and require expensive specialized equipment, and hence are used mostly as research tools, with limited utility in day-to-day medical practice. The current smartphone application, MyeloPath, was

borne out of hopes of filling this critical gap, the idea being that if we can more accurately measure the severity of DCM symptoms, we will be better able to study and treat this debilitating condition.

OBJECTIVE

To develop a smartphone-based application that objectively quantifies the severity of DCM symptoms, particularly by measuring a patient's functional capacities (i.e., physical ability to perform some task(s) in real-time), rather than relying on subjective patient self-report.

FUNCTIONALITY

MyeloPath harnesses the capabilities of sensors integrated into modern smartphones to provide an objective evaluation, with reported quantitative metrics, of the following domains of a patient's neurological function:

1. **Dexterity**
2. Balance
3. Gait

Dexterity

Description of tasks:	*Task 1:* Patient clicks on, and drags, a randomly positioned marker on the screen to a target location *Task 2:* Patient begins with index finger and thumb in 'pinch' position and spreads them open on the screen *Task 3:* Patient clicks on two markers on the screen (one using index finger and one using thumb) and 'pinches' fingers together; *Task 4:* Using a fine-tipped stylus, patient traces a circle on the screen
Sensor:	Touch screen
Reported metrics:	*Task 1:* Time (s), efficiency (%), maximal instantaneous finger velocity (px/s) *Tasks 2 and 3:* Maximal instantaneous finger velocity (px/s) *Task 4:* Tracing error (px)
Methodology:	*Task 1:* Time required to complete task is recorded in seconds; efficiency is calculated as length of shortest possible (most direct) path divided by length of path taken; maximal instantaneous finger velocity is derived directly from the Android API *Tasks 2 and 3:* Maximal instantaneous finger velocity is derived directly from the Android API *Task 4:* Tracing error is measured as the cumulative distance (px) between the circle and each point on the path traced by the user

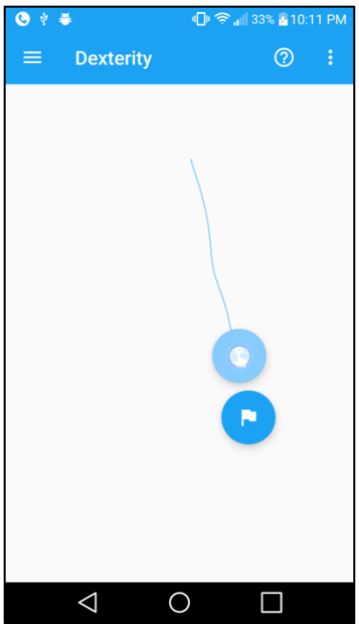

Figure 1. Dexterity Task 1

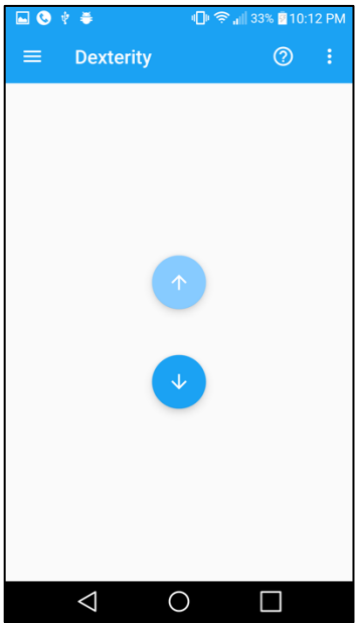

Figure 2. Dexterity Task 2

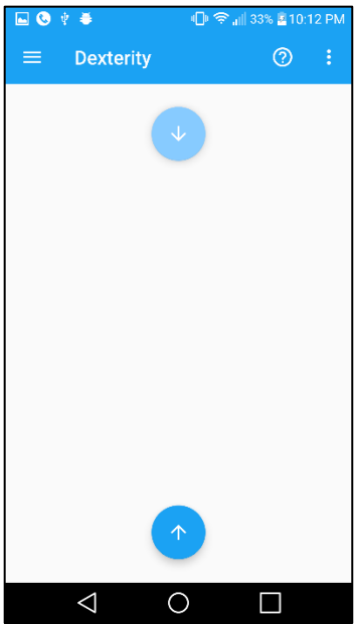

Figure 3. Dexterity Task 3

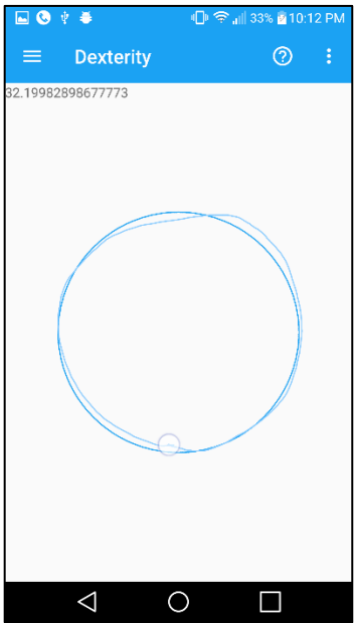

Figure 4. Dexterity Task 4

Balance

Description of task:	Patient places smartphone in their pocket; patient attempts to stand still with their feet together, arms placed by their side, and eyes closed for 5 seconds
Sensors:	Gyroscope
Reported metric:	Magnitude of unsteadiness 'sway'
Methodology:	For each of the three reference planes (X, Y, Z), the absolute value of angular velocity derived from the gyroscope is plotted by time and the integral is calculated; the sum of the integrals of

	absolute angular velocity by time for X, Y, and Z planes serves as a relative measure for the magnitude of unsteadiness

Figure 5. Starting screen for Balance

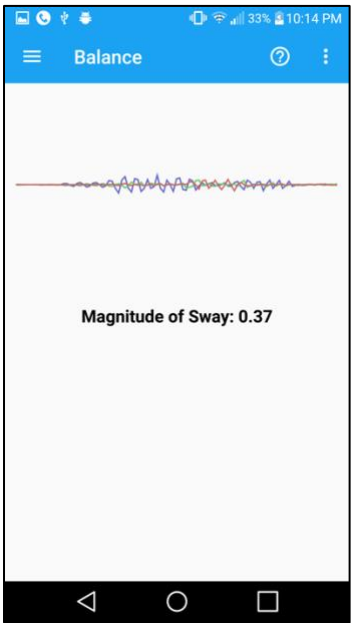

Figure 6. Balance task in progress

Gait

Description of task:	Patient places smartphone in their pocket *Task 1:* Patient walks in a straight line at a self-selected pace for 5 seconds *Task 2:* Patient walks heel-to-toe (as if on a tight rope) for 5 seconds
Sensors:	Step Detector (Task 1) Accelerometer (*Task 1*) Gyroscope (*Task 2*)
Reported metrics:	*Task 1:* Time (s), no. of steps, distance (m), step length (m), velocity (m/s), cadence (steps/min) *Task 2:* Magnitude of unsteadiness or 'wobble'
Methodology:	*Task 1:* Time will be fixed by asking the patient to walk for 5 seconds; no. of steps is provided directly by the built-in Step Detector on mobile phones; distance (displacement) is calculated as the double integral of acceleration by time; step length is calculated as distance traversed divided by number of steps; velocity is calculated as distance divided by time; cadence is calculated as number of steps divided by time *Task 2:* For each of the three reference planes (X, Y, Z), the absolute value of angular velocity derived from the gyroscope is plotted by time and the integral is calculated; the sum of the integrals of absolute angular velocity by time for X, Y, and Z planes serves as a relative measure for the magnitude of unsteadiness

Figure 7. Starting screen for Gait

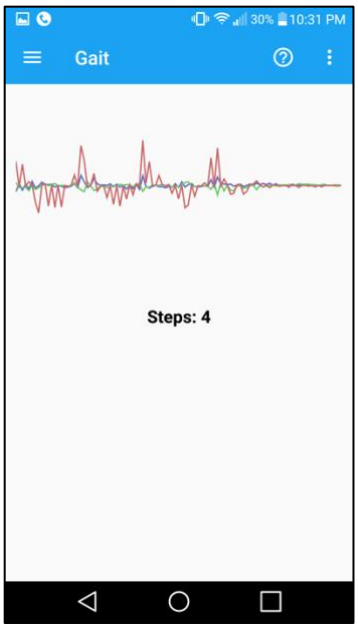

Figure 8. Gait Task 1

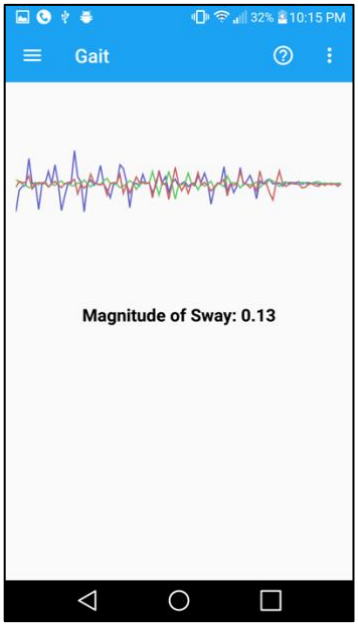

Figure 9. Gait Task 2

For each of the above tasks, the reported metrics are distilled into a single score ranging from 0 to 100, with higher values indicating better performance. Appropriate thresholds for each metric were determined by testing the application in three healthy (non-DCM) controls (members of our group). The three scores (one for each of dexterity, balance, and gait) are then averaged to yield a single unified 'DCM Severity Score' from 0 to 100. We recognize that these scores must be calibrated and validated by testing the application within a large sample of DCM and non-DCM patients; however, this was outside the scope of the current project. We do have future plans to conduct such a pilot study to be able to generate a validated 'DCM Severity Score'.

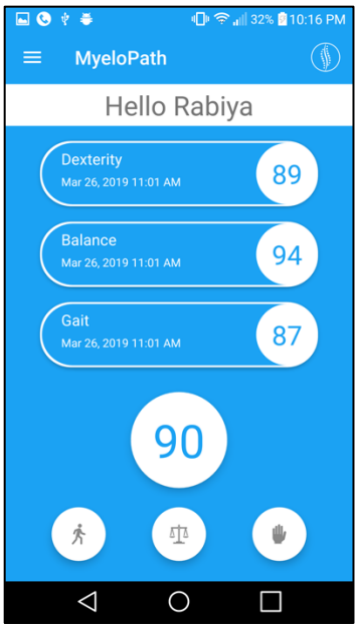

Figure 10. Home screen showing DCM Severity Score (90)

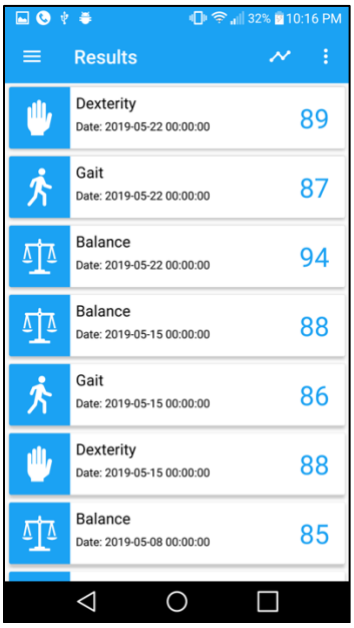

Figure 11. Results screen showing list of past tests and scores

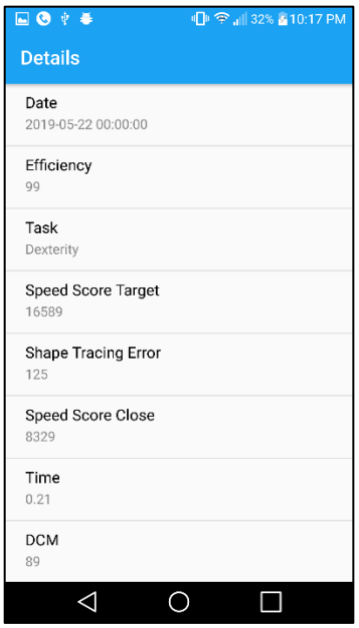

Figure 12. Detailed report for a single test

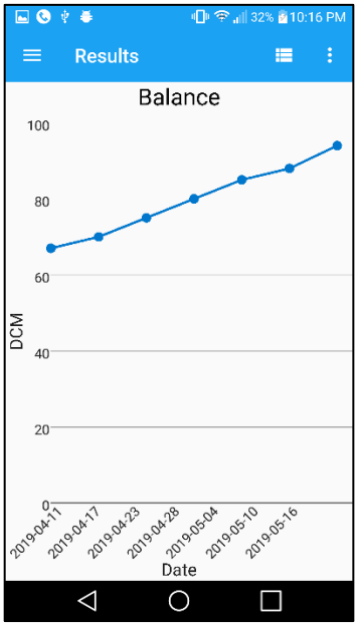

Figure 13. Historical plot of DCM Severity Scores over time

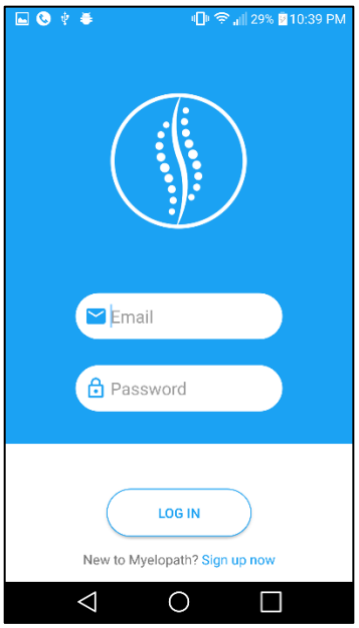

Figure 14. Login screen for existing patients

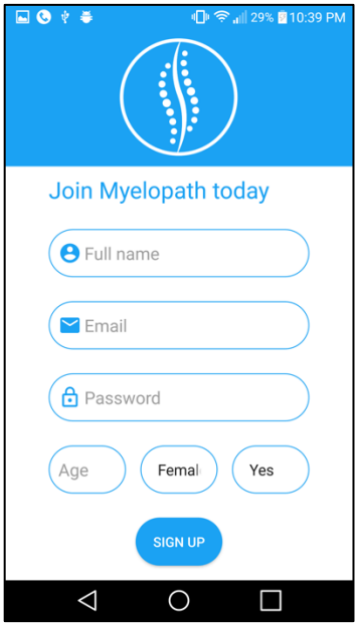

Figure 15. Registration screen for new patients

OVERALL DESIGN

Block Diagram

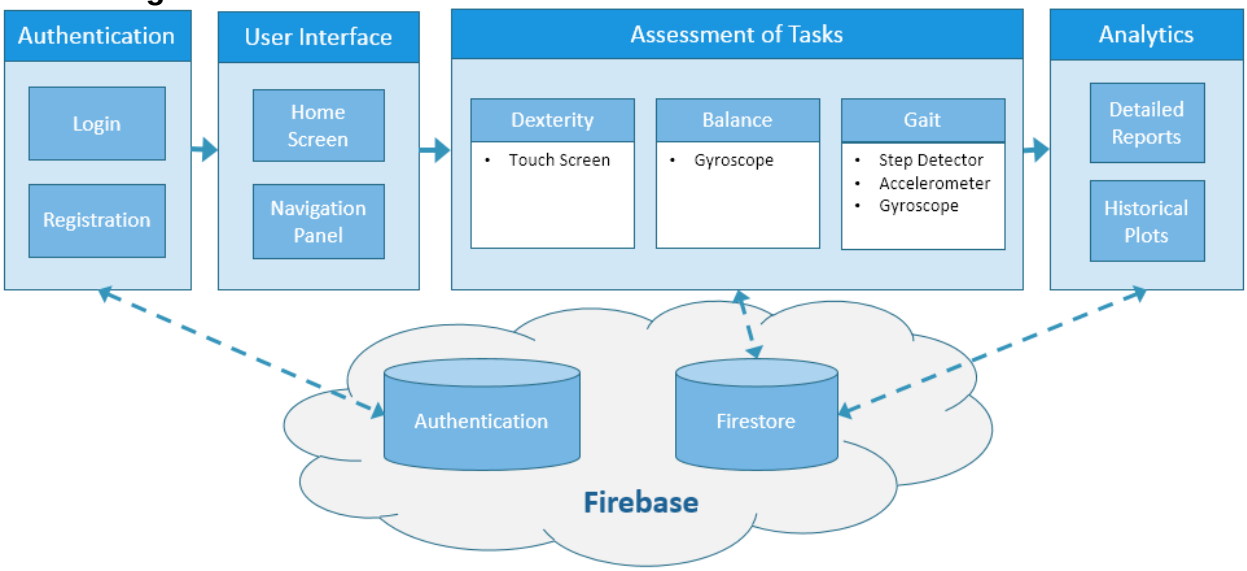

Figure 16. Block Diagram of MyeloPath app

Authentication: Consists of the Login and Registration screens. New patients will provide credentials to create a new account on Firebase. Existing patients will login using their email and password.

User Interface: Navigation within the app is facilitated by buttons on the Home screen and a panel on the left of the screen. These will allow the user to initiate one of the three Tasks.

Assessment of Tasks: The majority of the app consists of the Dexterity, Balance, and Gait modules. Each module uses varying sensors in the smartphone to collect a patient's biometric data.

Analytics: Patients can view how their DCM Severity Score was calculated on the Detailed Reports screen. Historical Plots provide an overview of their DCM Severity Scores over time.

Firebase: All parts of the app communicate with a Firebase server to store and retrieve patient credentials as well as biometric data.

REFLECTION

We learned a great deal through conducting this project. Perhaps most notably, for some of us, this was the first opportunity to truly work as part of a multidisciplinary team that brought together engineering and medicine. As a result, we learned many important elements of effective communication, including being able to express ideas in lay terms,

without relying on field-specific jargon. Further, we further honed skills in team work, namely breaking down a larger project into many smaller pieces, delegating these pieces to different group members, and finally putting the pieces together to form a unified product. On a more concrete educational level, we did have to conduct a literature review, which was led by the specialist, to delineate specific metrics of dexterity, balance, and gait that have been validated. For example, we learned of the evidence indicating that patients with DCM tend to demonstrate greater 'sway' of their center of gravity than healthy controls when their eyes are closed.[18]

If we were to repeat this project again, there are a few things we might do differently. First, we think it would have been beneficial to involve key stakeholders, namely DCM patients and clinicians who treat this condition, throughout the development phases of the application. This way, we could have ongoing feedback on how to refine the application to make it most sensitive as possible in detecting subtle changes in neurological function. Second, similar applications do exist for other neurological disorders, such as Parkinson's disease;[19] it may have been helpful to examine the source code for such applications (if publicly available) to be able to learn from, and perhaps adopt, elements of their methodology and code.

GROUP MEMBER CONTRIBUTIONS

Our group followed a fairly equal separation of tasks. As the specialist, Jetan Badhiwala provided leadership and direction on how this application may be designed to maximize relevance to patients, and secondly, to doctors. He conducted a review of the literature to identify very specific elements of gait and upper limb function testing that have previously been found to be important in discerning the severity of DCM. Further, he engaged in academic discussions with other specialists in the field of neurosurgery and spinal surgery, especially those within his own laboratory, to leverage their thoughts and expertise. Jetan scheduled our group's meetings based on our availability and provided access to the Conference Room within the Spinal Cord Injury Clinical Research Unit at the Toronto Western Hospital. Bei Cong (Chung) Zheng developed the backend of the application for the assessment of dexterity and balance, whereas Rabiya Noori did this for the gait assessment. Rabiya worked on the integration of the Firestore database in the application, and led the frontend/user interface development with support from Chung. Both programmers worked together on the contents in the Results screen. All group members were very active and engaged participants throughout the development of this application, testing the application and providing feedback.

SPECIALIST CONTEXT

I am a senior Neurosurgery Resident. I have taken a pause in my surgical training to pursue a PhD in clinical outcomes research related to spinal cord injury. DCM is one of the most common pathologies treated by neurosurgeons. During my surgical training, I performed approximately 20 to 25 operations for DCM per month. Further, in my research, I have given presentations at academic conferences and published several

peer-reviewed papers relating to DCM. A fair amount of this work has focused on patients with no or minimal symptoms, where there is truly equipoise in the best course of clinical management.[10,20-22] This is a very challenging patient population. On one hand, if a patient does not have any symptoms relating to their spinal cord compression, there is a lot to be lost if there is a surgical complication wherein the spinal cord is injured – indeed, it would be devastating to render a patient who was otherwise perfect, paralyzed from a surgical mishap. However, on the other hand, the ideal time to perform surgery for DCM is when symptoms are only mild, because intervention at this stage could prevent the development of otherwise permanent, irreversible neurological deficits. The problem is that current assessment methods are not sensitive enough to detect mild neurological impairment – these are mostly survey-type questionnaires. Our research group has therefore done much work to study surgical outcomes in patients with asymptomatic spinal cord compression or mild DCM, and further, to try and develop more accurate and sensitive assessment tools. The current application fits into this larger body of work. Our hope is that if we can detect subtle changes in neurological function in a seemingly 'normal' patient with imaging evidence of spinal cord compression, we may be able to intervene with surgery before more severe and permanent neurological injury has occurred. I therefore believe that MyeloPath fills a critical void in my field by providing a sensitive, objective assessment of patients with DCM that may easily be performed at the bedside or clinic.

FUTURE WORK

We would like to perform a pilot study of our application in 100 patients with DCM and 100 healthy (non-DCM) controls. Detailed metrics from each task (dexterity, balance, gait) would be recorded for each study participant. Further, all participants would complete standard clinical assessments, including the mJOA scale. This would allow us to calibrate the scores outputted by our application to standard clinical scales, and in doing so, provide a validation of our application. In addition, from the healthy controls, we would be able to derive normative values for our dexterity, gait, and balance scores.

With regard to additional capabilities, we would like to explore the possibility of having the application measure finger strength, namely 'pinch' strength, which we know from the literature, is adversely affected in individuals with DCM. We have investigated this further and know that certain smartphones, including the iPhone for example, are equipped with touch screens that can quantitatively measure the amount of pressure that is exerted. Our hope would be that the addition of this functionality further helps more sensitively assess the severity of DCM-related neurological disability.

SHARING OF INFORMATION

All group members agree to having the video and report posted publicly on the course website, but not the source code.

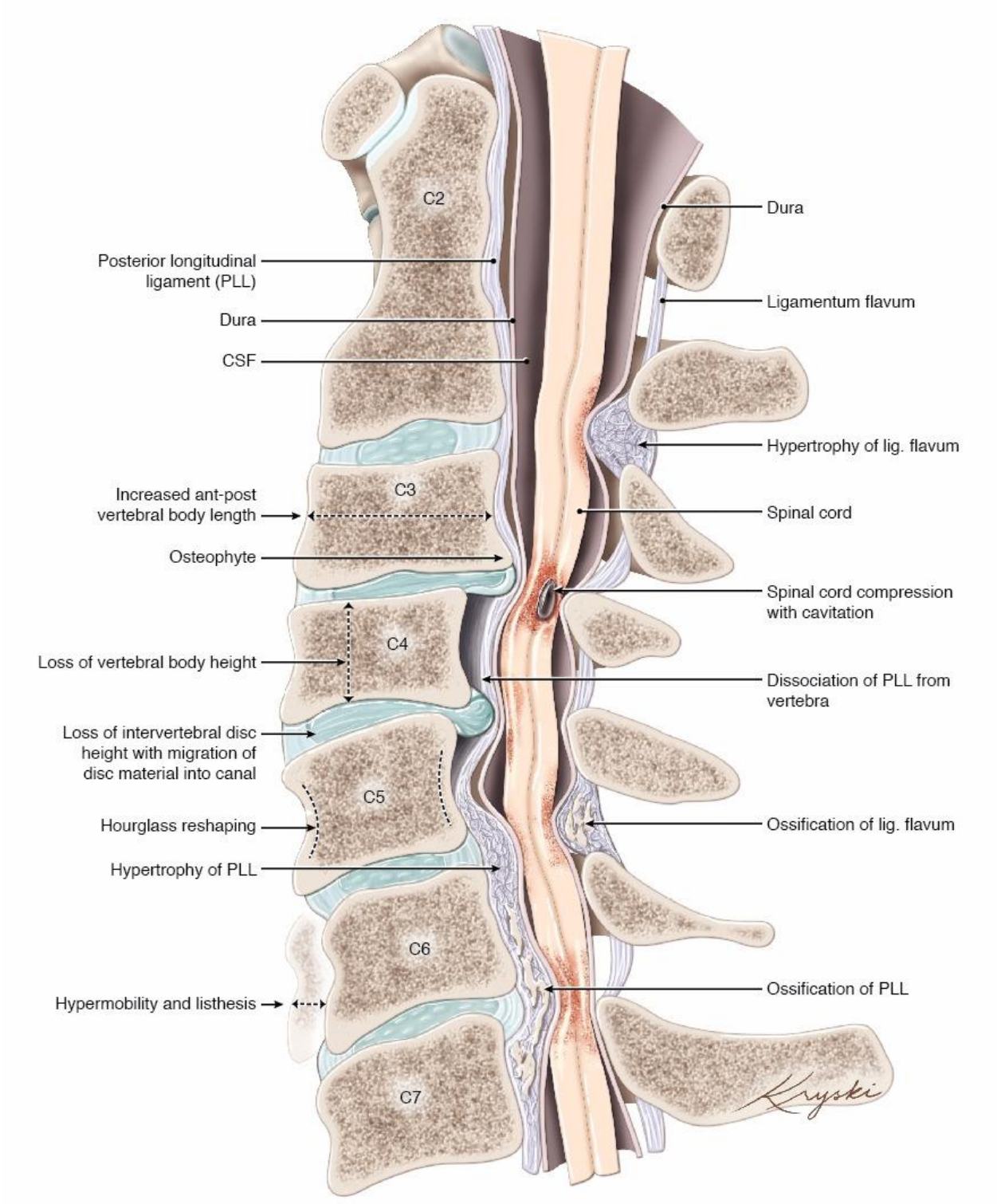

Figure 1. Pathological changes to the cervical spinal column and spinal cord in DCM. Reprinted from Nouri A, Tetreault L, Singh A, Karadimas SK, Fehlings MG. Degenerative Cervical Myelopathy: Epidemiology, Genetics, and Pathogenesis. *Spine (Phila Pa 1976).* 2015;40(12):E675-693.

Table 1. The modified Japanese Orthopaedic Association scale	
Motor dysfunction, upper extremity	
0	Inability to move hands
1	Inability to eat with a spoon, but able to move hands
2	Inability to button shirt, but able to eat with a spoon
3	Able to button shirt with great difficulty
4	Able to button shirt with slight difficulty
5	No dysfunction
Motor dysfunction, lower extremity	
0	Complete loss of motor and sensory function
1	Sensory preservation without ability to move legs
2	Able to move legs, but unable to walk
3	Able to walk on flat floor with a walking aid (cane or crutch)
4	Able to walk up and/or down stairs with handrail
5	Moderate-to-significant lack of stability, but able to walk up and/or down stairs without handrail
6	Mild lack of stability but walks with smooth reciprocation unaided
7	No dysfunction
Sensory dysfunction, upper extremity	
0	Complete loss of hand sensation
1	Severe sensory loss or pain
2	Mild sensory loss
3	No sensory loss
Sphincter dysfunction	
0	Inability to micturate voluntarily
1	Marked difficulty with micturition
2	Mild-to-moderate difficulty with micturition
3	Normal micturition

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