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**Manuscript title:** The use of smart technology in an online community of patients suffering from degenerative cervical myelopathy.

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**Running title:** Smart technology in degenerative cervical myelopathy

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Abstract

Background

Degenerative Cervical Myelopathy (DCM) is a prevalent and progressively disabling condition. Treatment is currently limited to surgery, the timing of which is not without controversy. New international guidelines advise all patients should undergo lifelong surveillance, with moderate to severe or progressive disease offered surgery. Long-term surveillance will place substantial burden on health services. Moreover, clinic assessments may risk misrepresenting disease severity.

The use of smart technology to monitor disease progression could provide an invaluable opportunity to lessen this burden and improve patient care. However, given the older demographic of DCM the feasibility of smart technology use is unclear.

Objectives

The aim of this study is to investigate current usage of smart technology in patients with self-reported DCM to inform design of smart technology applications targeted at monitoring DCM disease progression.

Methods

Google Analytics from the patient section of Myelopathy.org, an international DCM charity with a large online patient community, were analysed over a one-year period. A total of 15,761 sessions were analysed.

Results

In total, 39.6% of visitors accessed the website using desktop computer, 35.1% mobile and 25.3% tablet. Of the mobile visitors, 98.2% utilised a touchscreen device. A total of 53.7% of mobile visitors used iOS and 43.2% Android operating systems. Apple and Samsung were the most popular devices, utilised by 53.7% and 25.8% of visitors, respectively. Overall visitor age was representative of DCM trials. Smart technology was widely used by older visitors: 24.0% of mobile visitors and 60.5% of tablet visitors were 55 years or older.

Conclusions

Smart technology is commonly used by DCM patients. DCM applications need to be iOS and Android compatible to be available to all patients.
Degenerative cervical myelopathy (DCM) is a chronic and progressive neurological condition secondary to degenerative changes in the cervical spine causing cervical spinal cord compression[1];[2].

In classical descriptions DCM patients present complaining of a broad-based gait and clumsy hands[3];[4];[5]. In reality, symptoms are varied and often subtle, which contributes to significant under-diagnosis, misdiagnosis and delayed diagnosis[6]. This has prevented accurate characterisation of its epidemiology, but based on imaging studies, its prevalence could be as high as 5% in over 40s[6]. Ultimately, the condition is progressive and in extreme circumstances can lead to paralysis[5]. This significant disability severely impacts quality of life; a recent study found that quality of life in DCM patients is lower than in almost any other chronic disease, including cancer, diabetes and chronic lung disease[7].

At present surgical decompression is the only effective treatment for DCM. It is able to halt disease progression and provide some degree of improvement. However, despite surgery most patients will continue suffer from neurological deficits[8];[9], and therefore the timing of surgery is crucial[10]. If offered too late, this will expose patients to irreversible damage; if offered prematurely, surgery may expose patients to an invasive procedure with a risk of potential unintended effects. Moreover, DCM may develop at non-operated spinal levels in the future, for example due to adjacent segment degeneration.

Consequently, there is an increasing need for close monitoring in patients with DCM. New international guidelines recommend that for moderate to severe disease, surgery should be offered and patients monitored after surgery[10]. For mild disease, long-term follow up is recommended[10]. Surveillance of this large and increasing cohort of patients poses many problems, including a huge burden on clinical services. Moreover, snap-shot outpatient clinic assessments once or twice per year risk misrepresenting disease severity. In addition, current disease severity measures are poorly sensitive to change and poorly adapted to research studies, limiting outcomes for both present and future patients[11].

Smart technology offers a novel and innovative solution to this problem. Smart technology is increasingly prevalent in the general population: in 2017 it was estimated that there were almost 4 billion internet users worldwide[12]. Moreover, a recent survey found that 85% of the adult population of the United States own a mobile phone and 45% own a smart
A study of 300 participants seeking healthcare in an US emergency department found that 71% owned smartphones, of which 95% had apps and 44% had health apps[14]. Smart devices have highly sophisticated inbuilt technologies, including Global Positioning Systems, accelerometers, microphones, speakers and cameras capable of fulfilling medical assessments[15]. Smart technology has average to excellent accuracy in measuring a range of physical activities including differentiation of static activity, stair climbing, cycling, walking and running[16], allowing widespread use of smartphone apps in measuring biological parameters, diabetes, cardiac rehabilitation and falls in the elderly[15].

Users can input data at high frequency, making it much easier to detect change with time. Current DCM disease severity measures are relatively simple, focusing largely on gait and motor functioning, making them highly accessible for patients to understand and accurately score[17];[18]. Moreover, users appear motivated to engage with smart technology: 52% of smartphone users reporting using their smartphone to search for health information[13].

Such assessment tools may have additional benefits, transferring assessments to non-specialists to facilitate earlier diagnosis and may offer a useful research tool. There are also clear financial benefits; a report for the European Union estimated that mobile health could save 99 billion EUR in healthcare costs in the European Union and add 93 billion EUR to the EU GDP in 2017 if its adoption is encouraged[19].

Due to its degenerative nature, the average patient age undergoing surgery for DCM is in the mid 50s[2]. Currently available trials data suggests that the DCM patient demographic is approximately 60% male, 80% Caucasian with a mean ages of presentation reported as 56-64 years[20];[8]. Clearly, for smart technology to offer an immediate benefit it would need to be applicable to a high proportion of patients. Whether this is feasible for the current DCM population is unknown.

**Objectives**

This study aims to assess the current usage of smart technology in DCM patients, in order to ascertain the feasibility of introducing a smart technology-based assessment tool. We hypothesise that smart technology is utilised by DCM patients of all age groups.
Methods

Study Design

A cross-sectional observational study was conducted. All reporting adheres to the EQUATOR Network STROBE guidelines[21].

Setting

Data on visitor demographics to the patient section of Myelopathy.org (figure 1), an international myelopathy charity, were collected over a one-year period from April 2016 - April 2017 using Google Analytics (Google, California, USA). Myelopathy.org is designed for patients, professionals and carers and has a growing online community.

![Figure 1. Homepage screenshot from Myelopathy.org, an international myelopathy charity.](image)

Participants

DCM patients were identified by selecting visitors who accessed an e-survey landing page, intended for patients, hosted by Myelopathy.org[22]. This unique landing page required visitors to click through a description of the disease to confirm they had a diagnosis of DCM. A total of 15,761 website visiting sessions were analysed. Sessions were undertaken by 10,294 users, of which 10,261 were new users. Whilst many of the discarded users are likely patients, only the 744 users who clicked through the patient landing, page from the main website, were included in the analysis, due to greater certainty that they were in fact patients (figure 2).
Figure 2. A total of 15,761 sessions were analysed, 4.7% (744) of which involved the DCM patient survey page.

**Variables**

Data were collected on visitor demographics, device use, mobile device characteristics, mobile operating system, mobile manufacturer and visitor age range.

**Data Sources**

All data were extracted directly from Google Analytics software and analysed in Microsoft Excel (Office 365, Microsoft, Washington, USA).

**Bias**

No visitors were excluded. As a self-selected population, it is possible that non-DCM patients were included. However, given our selection process, we believe that this is likely to be very small and in the context of our large sample size unlikely to influence the overall results.

**Study size**

Overall 43,004 page views from 15,761 visits were analysed. A total of 10,261 new visitors were analysed, of which 744 visited the patient landing page via the Myelopathy.org homepage. All DCM patients over the 12-month study period were included.

**Statistical Methods**

Formal statistical analysis was deemed not appropriate.

**Ethics Approval and consent**

The study was ethically by Cambridge Human Biology Research Ethics Committee, University of Cambridge.
Results

1. **Participant Demographics**

Key demographic characteristics of DCM patients are summarised in table 1. In total, 29.8% of visitors were male. Age range was broad from 18 years to over 65 years. Overall visitor location was diverse. Patient visitors came from over 31 different countries, predominantly
the United States (34.1%) and United Kingdom (53.8%), representing 87.9% of overall visitors.

Table 1. Demographic characteristics of DCM patients visiting the patient survey page of Myelopathy.org.

<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>Total</th>
<th>Mobile</th>
<th>Tablet</th>
<th>Desktop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>n = 482</td>
<td>n = 192</td>
<td>n = 114</td>
<td>n = 176</td>
</tr>
<tr>
<td>18-24</td>
<td>26 (5.4)</td>
<td>7 (3.7)</td>
<td>4 (3.5)</td>
<td>15 (8.5)</td>
</tr>
<tr>
<td>25-34</td>
<td>49 (10.2)</td>
<td>22 (11.5)</td>
<td>2 (1.8)</td>
<td>25 (14.2)</td>
</tr>
<tr>
<td>35-44</td>
<td>79 (16.4)</td>
<td>50 (26.0)</td>
<td>12 (10.5)</td>
<td>17 (9.7)</td>
</tr>
<tr>
<td>45-54</td>
<td>134 (27.8)</td>
<td>67 (34.9)</td>
<td>27 (23.7)</td>
<td>40 (22.7)</td>
</tr>
<tr>
<td>55-65</td>
<td>109 (22.6)</td>
<td>31 (16.2)</td>
<td>34 (29.8)</td>
<td>44 (25.0)</td>
</tr>
<tr>
<td>65+</td>
<td>85 (17.6)</td>
<td>15 (7.8)</td>
<td>35 (30.7)</td>
<td>35 (19.9)</td>
</tr>
<tr>
<td>Gender</td>
<td>n = 487</td>
<td>n = 192</td>
<td>n = 115</td>
<td>n = 180</td>
</tr>
<tr>
<td>Male</td>
<td>145 (29.8)</td>
<td>53 (27.6)</td>
<td>22 (19.1)</td>
<td>70 (38.9)</td>
</tr>
<tr>
<td>Country of residence</td>
<td>n = 744</td>
<td>n = 261</td>
<td>n = 188</td>
<td>n = 295</td>
</tr>
<tr>
<td>United States</td>
<td>254 (34.1)</td>
<td>107 (41.0)</td>
<td>58 (30.9)</td>
<td>89 (30.2)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>400 (53.8)</td>
<td>117 (44.8)</td>
<td>120 (63.8)</td>
<td>163 (55.2)</td>
</tr>
<tr>
<td>Canada</td>
<td>29 (3.9)</td>
<td>10 (3.8)</td>
<td>4 (2.1)</td>
<td>15 (5.1)</td>
</tr>
<tr>
<td>Australia</td>
<td>12 (1.6)</td>
<td>5 (1.9)</td>
<td>3 (1.6)</td>
<td>4 (1.4)</td>
</tr>
<tr>
<td>India</td>
<td>6 (0.8)</td>
<td>4 (1.5)</td>
<td>0 (0)</td>
<td>2 (0.7)</td>
</tr>
<tr>
<td>Ireland</td>
<td>6 (0.8)</td>
<td>2 (0.8)</td>
<td>3 (1.6)</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td>Malaysia</td>
<td>4 (0.5)</td>
<td>3 (1.2)</td>
<td>0 (0)</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td>Other</td>
<td>33 (4.4)</td>
<td>13 (5.0)</td>
<td>0 (0)</td>
<td>20 (6.8)</td>
</tr>
</tbody>
</table>

2. Smart Technology Use

Device

The Myelopathy.org patient survey was accessed by desktop, mobile and tablet devices. A total of 35.1% (261) of visitors accessed the survey using a mobile phone, 39.6% (295) a desktop device and 25.3% (188) a tablet device.

Smart technology users

Of the smart technology (mobile or tablet) users, 98.2% utilised a touch-screen device. Whilst iOS (53.7%) and Android (43.2%) operating systems were dominant in their share of visitors, with a combined 96.9% of patient visitors utilising one of the two operating systems, use by device manufacturer was more diverse. Although Apple (53.7%) and Samsung (25.8%) were
the most popular device manufacturers, 20.5% of devices were produced by 22 other manufacturers. No manufacturer other than Apple or Samsung was utilised by more than 2.5% of visitors and 86.4% of patient visitors utilised devices from one of the top 5 most popular manufacturers, including LG (2.5%), Amazon (2.5%) and Motorola (2.0%), in addition to Apple and Samsung.

3. **Smart technology engagement across age groups**

Overall, visitor age range was broad (table 1), with 68% of visitors 45 years or older. The overall visitor modal age group was 45-54 years.

The patient visitor profile for each technology according to age is shown in figure 3. Modal age group was 45-54 years for mobile users, 65+ years for tablet visitors, and 55-64 for desktop visitors. All three device types were widely used amongst older patients, with 58.9% of mobile, 84.2% of tablet and 67.6% of desktop visitors 45 years or older. Of all tablet visitors, the number of visitors per age group increased with age, up to a peak in the modal 65+ age group. The number of desktop visitors per age group also tended to increase with age, whilst for mobile devices, the number of visitors per age group increased with age up to the modal age group of 45-54 years, before declining in older age groups.
Figure 3. Percentage age distributions of total users of each device. The percentage of visitors in each age group differed depending on device used.

Gender composition was 29.8% male (table 1). The modal age of both male and female patient visitors was 45-54 years. The number of visitors increased as age increased for both sexes, with males plateauing from the 35-44 years age group, whilst female visitors showing a clear peak at the 45-54 years group.

Almost identical age distributions were seen between visitor populations from the United States and United Kingdom. Modal age group was 55-64 years for US patient visitors and 45-54 years for UK patient visitors. A total of 75.0% of US patient visitors were 45 years or older, whilst 64.0% of UK visitors were 45 years or older.

Discussion

1. **Key results**

The use of smart technology is prevalent in DCM patients of all ages, with patients favouring portable devices such as mobiles and tablets. The distribution of technology usage across age groups differed, with mobiles favoured in middle age and tablet and desktop usage more common in later years. Android and iOS are the predominant mobile operating systems utilised by DCM patients.

2. **Generalisation of Findings**

From the outset, it is important to consider the limitations of this study and in particular whether this population represents DCM as a whole; an internet platform is a self-selected
population, both in terms of confirming the diagnosis of DCM and for which access requires technology usage.

Whilst this is a potential limitation, it is important to recognise that internet usage amongst older age groups is well described[23] and the focus was instead the use of smart technology, for which desktop users could act as a surrogate control group.

Additionally user age was representative of DCM trials, which frequently report mean patient ages of 56[8];[9]. In this study, 40.2% of overall visitors were 55 years or older and the modal visitor age was 45-54 years. Unfortunately, due to the limitations of Google Analytics, age is presented in age ranges and the age group 65+ is particularly broad and would benefit from sub-analysis.

Whilst the gender constitution differed (29.8% male compared to trial populations of between 60% and 65% male[8];[9]), gender did not influence the technology usage in this study. Additionally it has been shown that women utilise the internet for health information and support more widely than men[24];[25] We have previously shown this relates to the weighting of Facebook patient support groups, which are predominantly female and which were the most successful recruitment strategy[22].

There is a small risk that some visitors included did not in fact have DCM. However, the focused selection on those visitors accessing a survey, in which they had to click through a description of symptoms to confirm they had a diagnosis of DCM before accessing the patient survey page alongside the rational demographics makes this unlikely. Additionally we have previously shown that at present the platform is infrequently used by non-patients[26]. Therefore, any contribution from non-DCM patients is likely to be small and have a negligible influence on results.

Additionally, although users were mostly from the US or UK, equivocal findings from across the globe, shows potential for smart technology elsewhere too.

3. **The emerging role of smart technology for health, including DCM.**

The potential of smart technology for health is rapidly becoming established. There has been an explosion of health-related smart technology applications, aimed at a multitude of areas including education, medical assessment but also medical intervention[15].
To date much focus has been on educational applications, for patients and professionals, or simple assessments such as the inputting of survey data, simple sensor metrics such as physical activity or partnership with 3rd party technology, such as blood sugar monitors[27]. However simple, their usage is being shown to have significant clinical benefit with easy uptake by patients. For example, a recent systematic review of mobile and smart technology use in diabetes care found that the majority of interventions improved primary endpoints such as HbA1C and that technologies that interacted with both patients and providers were most likely to be successful[28]. A public opinion survey applied to a Greek population found strong significant effects of perceived usefulness, relative advantage of use and perceived ease of use of a smart m-health application[29]. Moreover, Anderson et al. utilised a semi-structured interview format to explore how health consumers use apps for health monitoring in Australia. They found that apps were used to monitor conditions including diabetes, asthma, depression, coeliac disease, blood pressure, migraine and menstrual cycle irregularity on an approximately weekly basis[30]. This clear potential and appetite is contributing to significant investment and rapid growth in mHealth[19], including more sophisticated systems.

This includes patients with DCM, where new guidelines[10] advise close surveillance yet current clinical assessments have shown poor responsiveness to change[11]. Laboratory gait-analysis is a quantitative assessment which is showing promise to overcome these limitations as it can provide a sensitive and reproducible measure of walking[31], is able to detect subtle progression[32], distinguish patients from healthy-controls[33], predict outcome after surgery[34] and predict disease progression[35][36] Researchers in the field of Parkinson’s disease have demonstrated that similar analysis can occur using smartphones[37],[38],[39], which would offer the additional benefit of continuous monitoring in a patient’s own environment.

Clearly a significant barrier to the uptake of any potential smart technology application would be its availability amongst the target audience. Therefore, the prevalence of smart technology among DCM patients in this study is a reassuring finding. However, it is worth noting that not all smart-technology has the same eHealth potential; for example, whilst desktops have input capabilities they may lack monitoring sensors; tablets may have similar monitoring capabilities as smart phones, but their larger size may preclude certain measurements such as pocket-mediated gait analysis. Additionally due to the requirement for web browsing, this
study has not captured the use of smart-watches, which also have significant mHealth potential [40].

**Conclusions**

Smart technology use is prevalent in DCM patients. An application to monitor DCM disease severity must be compatible with both iOS and Android and multiple device manufacturers. For greatest immediate uptake, both phone and tablet-compatibility are desirable, although this must be considered in the context of an application’s objectives. Whilst such an application is yet to be developed, this study shows that the user group is at least in possession of the necessary technology.

**References**


