PLOS ONE

RESEARCH ARTICLE

Can patient-reported profiles avoid unnecessary referral to a spine surgeon? An observational study to further develop the Nijmegen Decision Tool for Chronic Low Back Pain

Miranda L. van Hooff[1,2]*, Johanna M. van Dongen[3], Veerle M. Coupé[4], Maarten Spruit[5], Raymond W. J. G. Ostelo[3,4], Marinus de Kleuver[2]

1 Department Research, Sint Maartenskliniek, Nijmegen, The Netherlands, **2** Department of Orthopaedic Surgery, Radboud University Medical Center, Nijmegen, The Netherlands, **3** Department of Health Sciences and the Amsterdam Public Health research institute, VU University, Amsterdam, The Netherlands, **4** Department of Epidemiology and Biostatistics, VU University Medical Center, Amsterdam, The Netherlands, **5** Department of Orthopedic Surgery, Sint Maartenskliniek, Nijmegen, The Netherlands

* m.vanhooff@maartenskliniek.nl

OPEN ACCESS

Citation: van Hooff ML, van Dongen JM, Coupé VM, Spruit M, Ostelo RWJG, de Kleuver M (2018) Can patient-reported profiles avoid unnecessary referral to a spine surgeon? An observational study to further develop the Nijmegen Decision Tool for Chronic Low Back Pain. PLoS ONE 13(9): e0203518. https://doi.org/10.1371/journal.pone.0203518

Editor: Robert Daniel Blank, Medical College of Wisconsin, UNITED STATES

Received: August 14, 2017

Accepted: August 22, 2018

Published: September 19, 2018

Data Availability Statement: All relevant data are within the paper and its Supporting information files.

Funding: The present study is not funded by industry or any other commercial sponsors. MLvH, MS, and MdK received limited funding from the Innovation fund of Dutch healthcare insurers (grant number 2921). The funders had no role in study

Abstract

Introduction

Chronic Low Back Pain (CLBP) is a heterogeneous condition with lack of diagnostic clarity. Therapeutic interventions show small effects. To improve outcomes by targeting interventions it is recommended to develop a triage system to surgical and non-surgical treatments based on treatment outcomes. The objective of the current study was to develop and internally validate prognostic models based on pre-treatment patient-reported profiles that identify patients who either respond or do not respond to two frequently performed treatments (lumbar spine surgery and multidisciplinary pain management program).

Methods

A consecutive cohort study in a secondary referral spine center was performed. The study followed the recommendations of the PROGRESS framework and was registered in the Dutch Trial Register (NTR5946). Data of forty-seven potential pre-consultation (baseline) indicators predicting 'response' or 'non-response' at one-year follow-up for the two treatments were obtained to develop and validate four multivariable logistic regression models. The source population consisted of 3,410 referred CLBP-patients. Two treatment cohorts were defined: elective 'spine surgery' (n = 217 [6.4%]) and multidisciplinary bio-psychosocial 'pain management program' (n = 171 [5.0%]). Main inclusion criteria were age ≥18, CLBP (≥6 months), and not responding to primary care treatment. The primary outcome was functional ability: 'response' (Oswestry Disability Index [ODI] ≤22) and 'non-response' (ODI ≥41).

design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: All authors declare to have received limited support from Innovation fund of Dutch healthcare insurers for the submitted work, to have no financial relationships with any organizations that might have an interest in the submitted work in the previous three years, to have no other relationships or activities that could appear to have influenced the submitted work. The authors declare that Sint Maartenskliniek is neither a commercial company nor a commercial private clinic. As all hospitals in the Netherlands, the Sint Maartenskliniek is a non for profit foundation and a public hospital, accessible to all.

Results

Baseline indicators predictive of treatment outcome were: degree of disability (all models), ≥2 previous spine surgeries, psychosocial complaints, age (onset <20 or >50), and patient expectations of treatment outcomes. The explained variances were low for the models predicting response and non-response to pain management program (R^2 respectively 23% and 26%) and modest for surgery (R^2 30% and 39%). The overall performance was acceptable (c-index; 0.72–0.83), the model predicting non-response to surgery performed best (R^2 = 39%; c-index = 0.83).

Conclusion

This study was the first to identify different patient-reported profiles that predict response to different treatments for CLBP. The model predicting 'non-response' to elective lumbar spine surgery performed remarkably well, suggesting that referrals of these patients to a spine surgeon could be avoided. After external validation, the patient-reported profiles could potentially enhance timely patient triage to the right secondary care specialist and improve decision-making between clinican and patient. This could lead to improved treatment outcomes, which results in a more efficient use of healthcare resources.

Introduction

Low back pain (LBP) causes the highest global burden of all diseases[1] by imposing a substantial economic burden on individuals, employers, the healthcare sector, and society as a whole due to increased work absenteeism, healthcare expenditures, and disability insurance[2,3].

Chronic LBP (CLBP; i.e. persistent LBP lasting over three months[4,5]) is a heterogeneous condition, which lacks diagnostic clarity. It is a common complaint for which patients seek consultation in primary care[6]. Although many primary care treatment options are available, it is estimated that 60–80% of the patients experience persistence of CLBP complaints after one year[7,8] and many patients consult secondary care spine specialists for their problems. However, secondary care providers cannot reliably identify which patients will benefit most from which surgical or a non-surgical intervention, resulting in large practice variation [9–11]. Two frequently applied secondary care treatments are elective lumbar spine surgery and multidisciplinary bio-psychosocial pain management, e.g. combined physical and psychological (CPP) programs. In recent systematic reviews moderate quality evidence for small effects was found for both[10,11], but evidence is lacking on how to identify CLBP patients who are most likely to respond, or not, to these treatment options[9,11–13].

To improve decision-making, it has been recommended to develop a classification system (i.e. prognostic model)[14,15], based on patient profiles consisting of biomedical and psychosocial indicators that are thought to influence the outcomes of these interventions[12]. This system can be used for triaging CLBP patients to surgical and non-surgical secondary care specialists[9,11,13,16–19]. The American 'National Institutes of Health' (NIH) task force on research standards for CLBP recently supported this recommendation[20]. For this reason, the Nijmegen Decision Tool for CLBP (NDT-CLBP) has been developed[21] and implemented in the Dutch interface of SweSpine[22]. It consists of a web-based patient-reported screening questionnaire, in which indicators predicting treatment outcome are assessed, and includes systematic outcomes monitoring after treatment.

The purpose of this study is to develop and internally validate prognostic triage models for the NDT-CLBP, by identifying patient profiles, based on patient-reported indicators that either predict 'response' or 'non-response' to elective lumbar spine surgery, and 'response' or 'non-response' to a multidisciplinary bio-psychosocial treatment (i.e. an intensive CPP program).

Materials and methods

Study design

For the present observational study we used pre-consultation (baseline) and one-year follow-up data from a single institution spine outcome registry. Every CLBP patient referred to the outpatient orthopedic department routinely completes a web-based screening questionnaire before consultation. As part of routine outcomes monitoring, at one-year follow up after treatment, patients are asked to complete a web-based follow-up questionnaire, including various patient-reported outcome measures (PROMs). The screening questionnaire has been implemented in routine practice since May 2012 and data have been acquired systematically over time. The institution's internal review board approved the study. Ethical approval for this study was not required, as the Dutch Act on Medical Research involving Human Subjects does not apply to screening questionnaires that are part of routine clinical practice. Patient-data were obtained as a part of routine outcome monitoring for use in daily practice. All patients were informed on the procedure and had the opportunity to declare that (anonymized) data are not used for other purposes as scientific research. For this study, fully anonymized and de-identified data were obtained for analyses and report. During the course of the study, none of the researchers / authors had access to identifying information. We followed the recommendations of the PROGRESS framework[23] and of the TRIPOD statement[24]. The study is registered in the Dutch Trial Registry (NTR5946).

Study population

Data of patients who completed the questionnaire before consultation (baseline) between May 2012 and June 2014 were included, and one-year follow-up outcome data of treated patients were obtained. Treatment decision was based on standard care protocols, including patient history, the biomedical diagnostic phase (e.g. physical examination and imaging) and shared decision-making. From this source population, two distinct treatment cohorts were identified and included in the present study (Fig 1).

Lumbar spine surgery cohort. This cohort consisted of patients who underwent elective lumbar spine surgery (instrumented fusion with or without decompression). Complete baseline and follow-up data, were available for 219 patients (missing one-year follow up; n = 12 [5.2%]). Main inclusion criteria: age ≥18 years, CLBP (≥6 months) arising from degenerative lumbar spine disorders (including spinal stenosis, degenerative or isthmic spondylolisthesis or degenerative disc disease) confirmed by imaging, not responding to conservative treatment, with or without radiating leg pain.

Combined physical and psychological (CPP) program cohort. The CPP-program cohort comprised patients who participated in a multidisciplinary group-orientated 10-day residential program with a cognitive behavioral approach. The program included cognitive behavioral training, physical activities, and education[25]. Complete baseline and follow-up data were available for 171 patients (missing one-year follow up n = 8 [4.5%]). Main inclusion criteria: age ≥18, CLBP (≥6 months), not responding to primary care treatment, spine surgery is not an option, commitment to the program, which includes commitment to 'stop shopping', and willingness to change pain-related behavior.

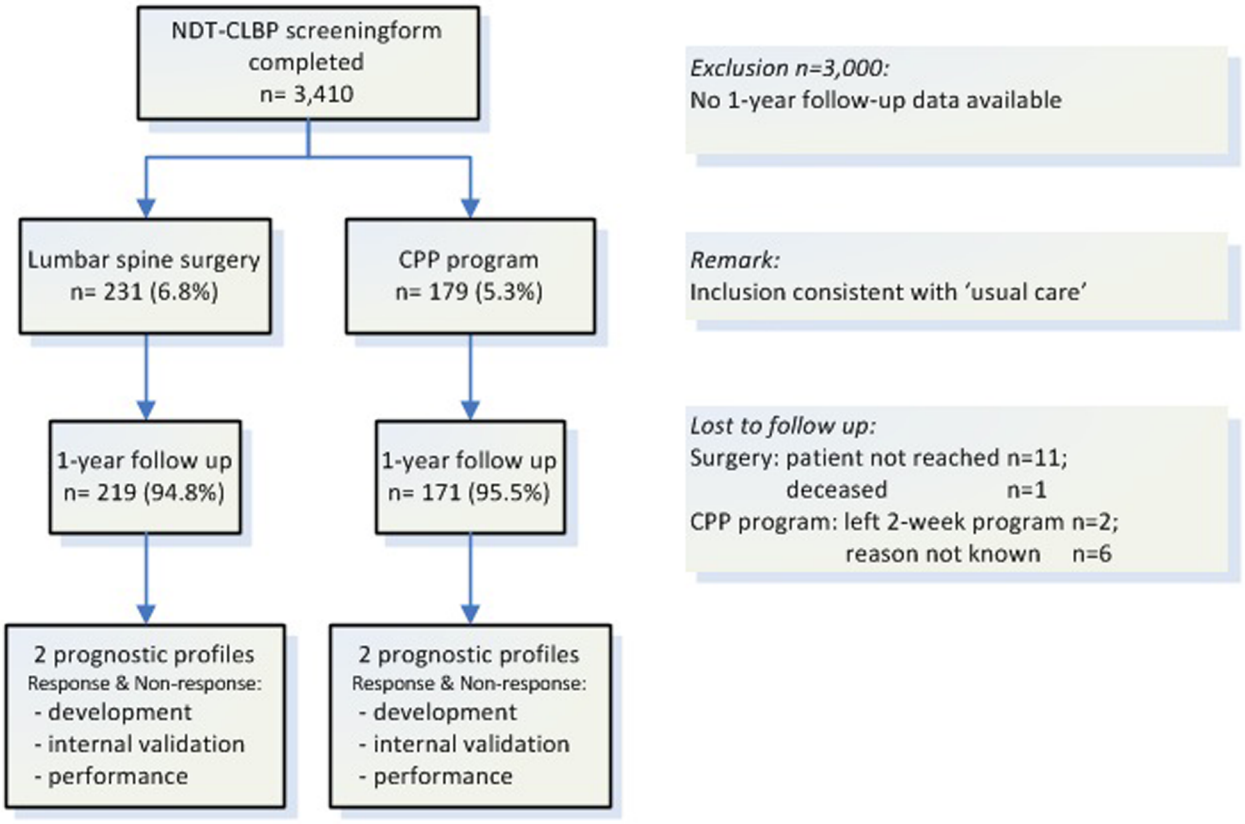

Fig 1. Flow of patient data throughout the study. *NDT-CLBP* Nijmegen Decision Tool for Chronic Low Back Pain. *CPP program* Combined Physical and Psychological program.

https://doi.org/10.1371/journal.pone.0203518.g001

Outcome measure and definition of the outcome at follow up

The primary outcome was 'response' and 'non-response' in terms of functional ability at one-year follow up, as measured with the condition-specific Oswestry Disability Index (ODI, version 2.1a in Dutch)[26,27]. The total ODI score ranges from 0 to 100, with higher scores indicating greater disability[28]. 'Response' (yes/no; coded 1/0) was defined as having an ODI$\leq$22 (i.e. successful, comparable to the 'normal' healthy population and an acceptable symptom state)[29,30]. 'Non-response' (yes/no; coded 1/0) was defined as having an ODI$\geq$41 (i.e. failure, comparable to 'severe disability' and persistence of CLBP)[31]. *Note*: the definitions of 'response' and 'non-response' are not complementary (i.e. a 'responder' is not the opposite of a 'non-responder').

Potential prognostic indicators

Forty-seven potential indicators, predicting treatment outcome or persistence of CLBP complaints, have been identified in a previous study and were included in the screening questionnaire of the spine registry (i.e. part of the NDT-CLBP)[21]. These indicators are classified into five domains (sociodemographic [n = 16], pain [n = 7], somatic [n = 14], psychologic [n = 8], and functioning & quality of life [n = 2]; see for more details S1 Table).

Statistical analysis

General

Patient characteristics were descriptively summarized. Complete-case analyses were deemed appropriate as less than 5% of the patients had missing values on one or more items. Before constructing and validating the final prediction models, the models' assumptions were checked[32].

Model development

To identify the prognostic indicators for 'response' and 'non-response', two-stage parsimonious backward logistic regression models were used. As all potential prognostic indicators were evidence-based and deemed clinically relevant (indicators mentioned in S1 Table), first statistical data reduction methods were applied. A univariate logistic regression analysis was performed and indicators with $p \leq 0.10$ were selected and subsequently included in an explorative oblique rotation principle component analysis (PCA)[33]. PCA was applied (1) to reduce the number of indicators and (2) to detect structure in the relationships between indicators, which is to classify indicators[32]. Second, the indicators identified in PCA with a factor loading ≥ 0.70 were included in the multivariable logistic regression analyses[32] (S2 Table). 'BMI' and 'smoking' were added in the multivariable analyses for surgery, because of the available evidence that high BMI[34–36] and smoking habit[35,37–41] are predictive for poor surgical outcome. Four multivariable logistic regression models were developed using a stepwise backward elimination method (stopping rule $p < 0.157$, i.e. Akaike 's information criterion), and subsequently internally validated and checked for their performance[14,15,32,42,43]. In each regression model, the outcomes 'response' (successful outcome) and 'non-response' (failure) were the dependent variables and the predictive indicators were the independent variables.

The models' performance was assessed by the percentage of variance explained (i.e. Nagelkerke's R^2); the agreement between the predicted probabilities of the outcome and the observed probabilities in the original data ($p > 0.05$; i.e. Hosmer-Lemeshow test [HL-test]); and by the models' discriminative ability (c-index: the area under the receiver operating characteristic curve [AUC])[32,43,44]. The c-index ranges from 0.5 (i.e. random prediction) to 1.0 (i.e. perfect prediction), where c-index >0.7 indicates that the model is acceptable[32].

An internal validation method with a bootstrap procedure (500 samples) was used to estimate the amount of over-fit. A slope value was calculated (i.e. closer to 1.0, less over-optimism)[43,44], and used to correct and shrink the regression coefficients, the R^2, and the c-index[15,32,42,44].

Except for the model's internal validation, performed in R (version 3.2.2. for Windows) and the scatter plots, created in STATA (version 12.0 for Windows; StataCorp, College Station, Texas, USA), statistical analyses were conducted in SPSS (version 22.0; IBM Corp, Amonk, New York, USA).

Results

Population at baseline (Tables 1 and S3 for complete overview)

The source population consisted of 3,410 referred patients who all completed the screening questionnaire and who consulted a spine surgeon. A total of 390 CLBP patients were included (mean age 49.9 [SD 13.6] years; 63.8% women; mean ODI 44.2 [SD 14.6]) and had lumbar spine surgery (n = 219, 6.4% of total population) or entered the CPP program (n = 171, 5.0% of total population).

Functional outcomes at one-year follow up (Tables 1 and 2; Fig 2A and 2B)

The mean ODI of the surgery cohort improved from 43.5 (SD 15.5) at baseline to 30.4 (SD 18.7) at one-year follow up, and the mean ODI of the CPP-program cohort improved from 45.1 (SD 13.5) to 22.7 (SD 17.5) (Tables 1 and 2).

Self-reported patient profiles

In Table 3 the final prognostic models and their performances are shown. For all four models the data fit well (HL-tests not significant). The final models showed low explained variances (R^2), but overall acceptable performances (c-index). The slope values for the surgical 'response' and 'non-response' models showed less over-optimism then those for the CPP program (respectively 0.89 and 0.85 versus 0.79 and 0.75).

Lumbar spine surgery

- Model predicting 'response' (c-index = 0.77; R^2 = 30%): less functionally disabled (i.e. lower ODI), being employed, positive outcome expectations, and a Red Flag for age (i.e. age onset <20 or >50).

Table 1. Main baseline patient characteristics.

		Source population	Lumbar spine surgery	CPP program
Domain	**Characteristics**	**All (n = 3,410)**	**All (n = 219)**	**All (n = 171)**
Sociodemographic	Age (years) [mean (SD) min-max]	50.8 (14.8) 18–84	53.6 (14.2) 15–83	45.1 (11.1) 20–71
	Gender Female [n (%)]	1,981 (58.1)	143 (65.3)	106 (62.0)
	Previous lumbar spine surgery—(Yes) [n(%)]	1,162 (34.1)	96 (43.8)	63 (36.8)
	Employed (Yes) [n(%)]	2,251 (66.0)	107 (48.9)	95 (55.6)
Pain	Duration—Back pain [n(%)]			
	3–12 months	729 (21.3)	44 (20.1)	16 (9.4)
	1–2 years	498 (14.6)	29 (13.2)	21 (12.3)
	> 2 years	2,183 (64.0)	146 (66.7)	134 (78.4)
	Duration Back pain >2 yrs [n(%)]			
	No	662 (19.4)	41 (18.7)	16 (9.4)
	2–10 years	1,523 (45.2)	107 (48.8)	83 (48.6)
	> 10 years	1,205 (35.3)	71 (32.4)	72 (42.1)
	NRS Back pain intensity [mean (SD) min-max]	7.0 (2.0) 0–10	6.9 (1.2) 0–10	7.6 (1.2) 3–10
	NRS Leg pain intensity [mean (SD) min-max]	5.4 (3.2) 0–10	6.1 (2.9) 0–10	5.4 (2.9) 0–10
Somatic	Co-morbidities—None [n(%)]	2,424 (71.1)	166 (75.8)	127 (74.3)
	≥ 1 Red Flag (Yes) [n(%)]	3,146 (92.3)	203 (92.7)	155 (90.6)
Psychological	SBT [n(%)]			
	Low risk	1,486 (32.6)	40 (18.3)	25 (14.6)
	Moderate risk	814 (23.9)	105 (47.9)	86 (50.3)
	High risk	1,110 (32.6)	74 (33.8)	60 (35.1)
	Expectations–recovery (Yes) [n(%)]	2,031 (59.6)	147 (67.1)	94 (55.0)
Functioning & Quality of life	ODI [mean (SD) min-max]	42.7 (16.1) 0–98	43.5 (15.5) 6–90	45.1 (13.4) 12–88
	SF36 PCS [mean (SD) min-max]	28.9 (8.3) 4–64	28.6 (7.5) 13–50	28.5 (6.1) 9–43
	SF6D [mean (SD) min-max]	0.576 (0.094) 0.294–0.921	0.572 (0.099) 0.296–0.892	0.561 (0.080) 0.366–0.843
	EQ5D [mean (SD) min-max]	0.447 (0.298) -0.329–1.000	0.444 (0.282) -0.204–0.893	0.405 (0.284) -0.134–0.843

ODI Oswestry Disability Index (version 2.1a in Dutch); *SBT* STarT Back Screening Tool (Dutch); *SF6D* Short Form 6 Dimensions; *SF36 PCS* Short Form 36 –Physical Component Scale; *EQ5D* EuroQol 5 Dimensions

https://doi.org/10.1371/journal.pone.0203518.t001

Table 2. Patient-reported outcomes at one year follow up.

	Lumbar spine surgery	CPP program
PROMs	**All n = 219**	**All n = 171**
NRS Back pain intensity [mean (SD) min-max]	4.4 (4.1) 0–10	4.2 (2.4) 0–9
ODI [mean (SD) min-max]	30.4 (18.7) 0–84	22.7 (17.5) 0–64
SF-36 PCS [mean (SD) min-max]	35.9 (10.0) 13–60	61.4 (20.5) 19–77
SF-36 MCS [mean (SD) min-max]	45.9 (10.9) 13–64	72.8 (18.1) 16–79
SF6D [mean (SD) min-max]	0.648 (0.130) 0.662–1.000	0.696 (0.125) 0.381–0.948
'response'—ODI ≤22 [n(%)]	82 (37.4)	86 (50.3)
'non-response'—ODI ≥41 [n(%)]	62 (28.3)	30 (17.5)

PROMs Patient-reported outcome measures *NRS* Numeric Rating Scale *ODI* Oswestry Disability Index (version 2.1a in Dutch) *SF36 PCS* Short Form 36—Physical Component Scale *SF36 MCS* Short Form 36—Mental Component Scale *SF6D* Short Form 6 Dimensions

https://doi.org/10.1371/journal.pone.0203518.t002

- Model predicting 'non-response' (c-index = 0.83; R^2 = 39%): more functionally disabled (i.e. higher ODI), ≥2 previous spine surgeries, a moderate or high risk on STarT Back screening tool, a Red Flag for age (i.e. age onset <20 or >50), self-reported spinal deformity, and self-reported reduced muscle strength.

CPP program

- Model predicting 'response' (c-index = 0.72; R^2 = 23%): less functionally disabled (i.e. low ODI), strong self-reported agreement with somatization, a little distressed, and self-reported paresthesia in the legs.
- Model predicting 'non-response' (c-index = 0.77; R^2 = 26%): more functionally disabled (i.e. high ODI), self-reported agreement with somatization and extreme distress.

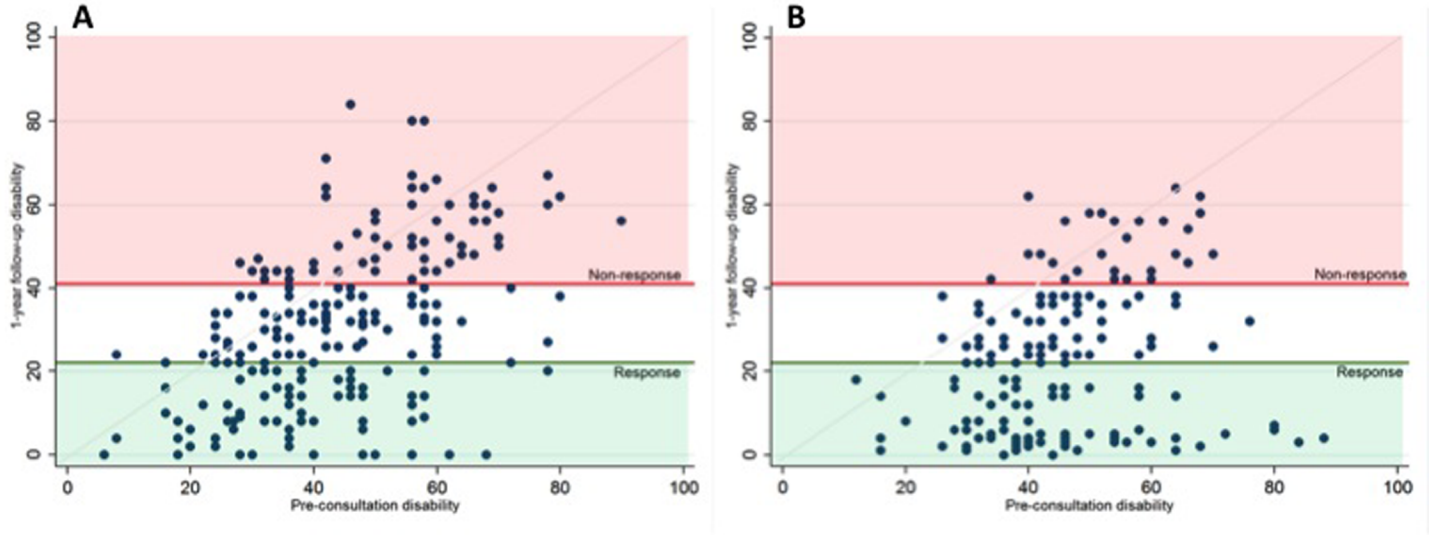

Fig 2. Functional status (ODI). (A) *Lumbar spine surgery cohort (n = 219)* and **(B)** *CPP-program cohort (n = 171). ODI* Oswestry Disability Index; *disability* is measured with the ODI. The *x-axis* represents pre-consultation disability and the *y-axis* the one-year post-treatment disability. The *red area* above the *red horizontal line* represents 'non-response' (ODI≥41) and the *green area* under the *green horizontal line* represents 'response' (ODI≤22).

https://doi.org/10.1371/journal.pone.0203518.g002

Table 3. Multivariable 'response' and 'non-response' models for lumbar spine surgery and combined physical and psychological (CPP) program.

	Spine Surgery								CPP program							
	Response: ODI ≤22				Non-response: ODI ≥41				Response: ODI ≤22				Non-response: ODI ≥41			
	B (SE)	OR	95% CI	p-value	B (SE)	OR	95% CI	p-value	B (SE)	OR	95% CI	p-value	B (SE)	OR	95% CI	p-value
ODI–screening	-0.04 (0.01)	0.96	0.94–0.98	<0.001	0.09(0.02)	1.09	1.05–1.13	<0.001	-0.04(0.01)	0.97	0.94–0.99	0.01	0.07 (0.02)	1.07	1.03–1.11	<0.001
Previous lumbar spine surgery																
n = 1 n ≥ 2 *reference*: *n = 0*	-0.49 (0.39) -1.67 (0.52)	0.62 0.19	0.29–1.32 0.07–0.52	0.21 0.001	0.32 (0.45) 1.49 (0.47)	1.41 4.25	0.57–3.51 1.68–10.75	0.46 0.001								
Employed	0.73 (0.33)	2.08	1.08–3.98	0.03												
STarT Back–screening																
Moderate risk High risk *reference*: *Low risk*					-1.66 (0.60) -1.08 (0.65)	0.17 0.29	0.05–0.58 0.08–1.10	0.01 0.07								
Somatisation																
Disagree Agree Strongly agree *reference*: *Strongly disagree*									0.88 (0.53) 0.32 (0.44) 1.30 (0.64)	2.42 0.73 3.67	0.86–6.83 0.31–1.72 1.04–12.94	0.10 0.47 0.04	0.20 (0.86) 1.25 (0.66) 1.51 (1.11)	0.82 3.48 0.22	0.15–4.45 0.96–12.65 0.03–1.95	0.82 0.06 0.17
Distress																
Yes, a little Yes, extremely *reference*: *No*									0.52 (0.38) -1.31 (0.64)	1.68 0.27	0.79–3.56 0.08–0.95	0.18 0.04	0.36 (0.55) 1.26 (0.02)	0.70 3.54	0.24–2.04 0.96–12.97	0.51 0.06
Expectations—recovery	1.17 (0.37)	3.22	1.57–6.69	0.001												
Red Flag																
Age (onset <20 or >50) Deformities	0.88 (0.33)	2.41	1.25–4.64	0.01	-1.16 (0.39) 0.84 (0.43)	2.41 2.61	1.25–4.64 1.09–6.23	0.01 0.03								
Neurological function																
Reduction muscle strength					0.92 (0.39)	2.50	1.16–5.36	0.02								
Paresthesia									0.85 (0.37)	0.43	0.21–0.88	0.02				
Intercept	0.05 (0.61)				-3.89 (0.68)				1.91 (0.75)				-5.59 (1.16)			
Model performance			*Model*	*Corrected*			*Model*	*Corrected*			*Model*	*Corrected*			*Model*	*Corrected*
Explained variance (Nagelkerke R^2)			0.33	0.30			0.43	0.39			0.26	0.23			0.32	0.26
c-index			0.80	0.77			0.85	0.83			0.76	0.72			0.81	0.77
Calibration																
Hosmer and Lemeshow			X^2 (8) = 3.51	p = 0.90			X^2 (8) = 11.04	p = 0.20			X^2 (8) = 6.09	p = 0.64			X^2 (8) = 8.92	p = 0.35
Slope value			0.89				0.85				0.79				0.75	

ODI Oswestry Disability Index (version 2.1a in Dutch); *OR* Odds Ratio; *CI* Confidence Interval

https://doi.org/10.1371/journal.pone.0203518.t003

Discussion

We present a tool to support triage of CLBP patients, based on their patient-reported pre-consultation profiles, to surgery and to a conservative treatment option (i.e. Nijmegen Decision

Tool for Chronic Low Back Pain [NDT-CLBP]). To our knowledge, this is the first study to report such a tool, the development of which has been previously recommended[9,11–13]. We identified and internally validated pre-consultation patient-reported profiles that are predictive for either 'response' or 'non-response' to elective lumbar spine surgery and to a multidisciplinary bio-psychosocial treatment (a combined physical and psychological [CPP] program). Results indicate that different subgroups of patients could be identified in the heterogeneous CLBP population, without regard for the 'anatomic' of etiopathogenic diagnosis.

A remarkable finding is the good performance of the 'non-response' model for spinal surgery (R^2 = 39%; c-index = 0.83; slope value 0.85). This indicates that the profile, based on patient-reported characteristics, seems accurate in identifying patients who are likely not to respond to surgical intervention. Within the source population (n = 3,410) of this study, 4.3% fulfil this patient-reported profile. If this profile remains stable after external validation, future CLBP patients who might not respond to surgery could be identified relatively well in an early phase, even before the patient consults the medical specialist. This could potentially change current practice; based on the profile, these patients could be triaged to a non-surgical medical spine specialist.

Overall, the final models' performance was acceptable (all c-indexes satisfactory [>0.7]) and the explained variances of the surgical profiles were modest (R^2 = 30–39%). However, the explained variances for the CPP-program models were rather low (R^2 = 23–26%), which means that the predictive indicators only explain a fraction of the variance in outcome between patients. This was expected as only patient-reported data were used to develop the prognostic models and previous studies evaluating single treatment prediction models, have reported similar explained variances (R^2 = 9% to 42%)[45–50]. Other indicators that are known to play a role in determining the outcome, which we intend to identify in the subsequent diagnostic phase, were not included in the models (e.g. specific diagnosis [e.g. degenerative spondylolisthesis, spinal stenosis] and clinical phenotypes, related to imaging [Modic changes] and biochemistry [biomarkers and genotypes])[51]. Future research should examine whether these indicators can extend and improve the current models, in order to have a reliable two-phased decision tool (1. triage to specialist and 2. based on diagnostics selection for treatment; Fig 3) with a correct combination of biomedical and psychosocial indicators. Then, stratification and personalized spine care might be achieved.

Comparison with previous literature

Although several single treatment prognostic models for CLBP have been developed predicting the outcome of lumbar spine surgery[35,41,45,46,49,52–58] or multidisciplinary bio-psychosocial programs[47,48,50,59,60], we found no studies on prognostic models for different treatment options, which makes this study unique. Some of the studies found used predictive indicators derived from pre-treatment questionnaires[46–48] but the questionnaires and the outcome definitions used differed, which hamper comparison with the current study. The consistent finding that pre-treatment level of functioning (ODI) is predictive for the outcome in all the models is consistent with previous studies in spine surgery[41,46,49,56] and multidisciplinary bio-psychosocial programs[47,48,60]. However, other predictive indicators identified in these studies varied depending on the purpose of the study, and with that, on the choice of potential predictive factors derived from screening questionnaires, diagnostic phase and/or the intervention.

Although the outcomes 'response' and 'non-response' are defined differently in literature, consistent with previous studies important contributing factors for the surgical models were age [35,41,45,46,54,56,58], being employed[56,61], outcome expectancy[49,62–64], and previous

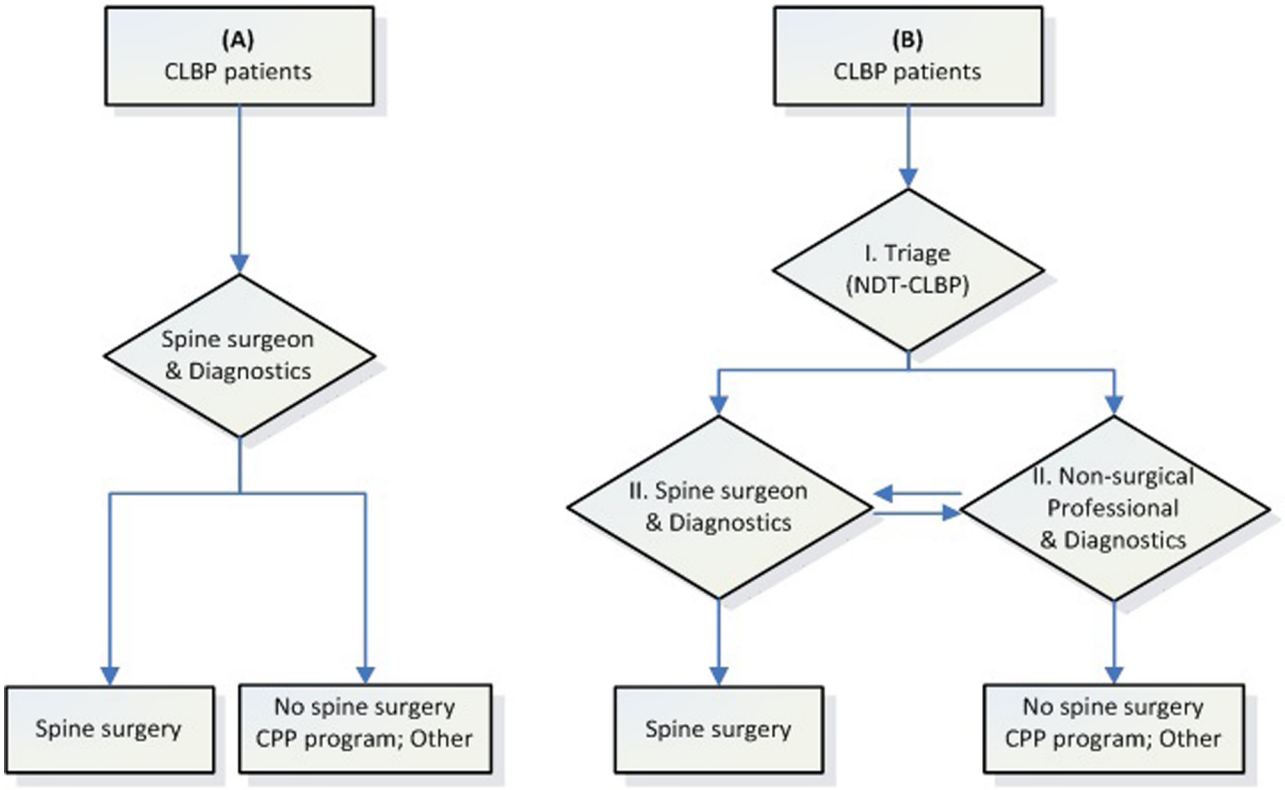

Fig 3. The process of patient triage without (A) and with (B) the Nijmegen Decision Tool for Chronic Low Back Pain (NDT-CLBP; a two-staged decision process to guide diagnostics and treatment). *CPP program* Combined Physical and Psychological program.

https://doi.org/10.1371/journal.pone.0203518.g003

lumbar spine surgery[41,54,56,58]. In the current study age <20 and >50 years was defined as a 'red flag' and was used as a screening question among other red flag screening questions (e.g. trauma; S1 Table). A recent paper by Premkumar et al. the authors confirmed an association between a positive answer to recent trauma and age >50 years and vertebral fracture as clinical (red flag) diagnosis [65], supporting the use of age and trauma as screening questions for patient triage to a surgeon for further diagnostics. Recently, Zehnder et al. found that an increasing number of previous surgeries were significantly associated with a less favorable outcome one year postoperatively. We found that two or more previous spine surgeries contribute substantially to a high risk of non-response to spine surgery. Patients with a history of prior spinal surgery should be critically evaluated before undergoing further spinal surgical interventions and the benefits of surgery should be carefully weighed up against the risks, since the outcome is predicted to be less favorable than for first-time procedures[58]. To avoid future often expensive revision surgery the NDT-CLBP seems appropriate to early identify patients 'at risk' and could contribute to 'getting it right first time' [66].

Growing evidence indicates that high BMI[35,36,41,56,58,67] and smoking [35,37–41,41,45,46,56,58,61] are predictive of a poor surgical outcome. However, we found no predictive value in the surgical non-response model for these indicators. A possible explanation could be that high BMI and smoking are predictive for post-operative complications, but might not diminish the final functional outcome. It could also be that self-reported BMI and smoking, as used in the current study, are less accurate than the use of

objective measures[68–71], which would result in underestimation of their contribution to poor outcome and non-response in these cohorts.

Consistent with previous studies, predominantly psychological indicators were found to be predictive of the outcome of the CPP program, irrespective of the outcome definitions used [47,50], but there is a lack of high quality studies addressing this topic[50].

Remarks on our study: Strengths and weaknesses

Strengths. An important strength of this study is that the NDT-CLBP is a first attempt to address a frequently recommended research theme: development of a classification system that is able to predict which CLBP patients benefit most from surgical or non-surgical interventions[9,11–13]. Furthermore, the potential predictive indicators used to derive the final prognostic models were based on scientific evidence and multidisciplinary consensus[21] and comply with the recommendation to use a standard set of metrics for outcome reporting that matter to patients[72]. Patient outcome data and data of the potential predictive indicators were prospectively and systematically collected in a large web-based spine outcome registry, and a high response rate on the primary outcome measure (95%) at one-year follow up was achieved. We developed and internally validated parsimonious prognostic models, based on clinical relevance and corrected the models and the performance measures for over-optimism. To develop the prognostic models, we used the ODI as a single primary outcome to define 'response' and 'non-response' using evidence-based cut-off values. The application of these two distinct and strict absolute thresholds as outcome criteria is unique. In previous studies various measures of change on the ODI were used as an outcome, e.g. percentage improvement relative to the ODI baseline value[60] or reaching a threshold for minimal important change to indicate treatment success[46,73] or to indicate deterioration[41]. However, in the use of change measures methodological issues such as baseline-dependency are encountered [74]. This means that patients with severe disability could improve for example 10 points[75] or 16 points[60] on the ODI, whilst in fact they are still functionally disabled. In decision-making for interventions we think strict absolute thresholds are needed for clinical interpretations as 'normal' or 'healthy' state ('response') or persistence of CLBP complaints ('non-response').

Weaknesses. This study was performed in a single institution, which might result in limited generalizability to other secondary or tertiary settings treating CLBP patients. In line with the phases of prognostic research[42,43,76,77], future studies are planned to test the generalizability of the prognostic patient-reported profiles[14,43,44], to explore the interaction of these profiles between treatments, and to analyze their budget-impact and cost-effectiveness. Second, as recovery of functioning is a main goal in clinical practice we defined functional ability as the primary patient-related outcome domain of surgical and non-surgical interventions. However, other outcome domains might also be relevant in spine care (i.e. pain, health-related quality of life[72,78–80], complications[72,80], repeat spine surgery, work status, and analgesic use[72]). Thirdly, patient-reported red flags are part of the screening questionnaire of the NDT-CLBP [21] and recommended in international guidelines [16–18]. The present study shows that most of the patients with CLBP (92%; Table 1) have at least one positive red flag but do not have a serious underlying condition. Taking the guideline recommendations literally could cause harm (e.g. unnecessary diagnostics, unnecessary exposure to radiation, unnecessary treatments, including surgery). In a recent paper by Premkumar et al. [65] the authors concluded that while a positive response to a red flag question might indicate the presence of disease, a negative response to 1 or 2 red flag questions does not meaningfully decrease the likelihood of a red flag diagnosis. We agree with the authors that caution should be taken against the use of red flags alone as a screening tool CLBP is characterized by a complex system

of multiple interacting bio-psycho-social indicators. Using 'red flags' with binary yes/no outcomes, does no justice to this complexity, oversimplifies the problem, and may harm patients. For example, in a certain context and combination of influencing factors, age may be a red flag, and in another situation it may not. Furthermore, after screening using a triage tool, a clinical assessment will always be needed, which will provide significant further input for decision making. The screening tool itself will never come to a diagnosis. We expect that combinations of 'flags' and clinical features, determined in the diagnostic phase, might be more informative to assist in clinical decision-making. This will be further explored in the second phase of the NDT-CLBP (Fig 3) when patient profiles for decision to treatment, rather than triage alone, will be analyzed and built. Fourth, per prognostic model a relatively high number of potential predictive indicators (i.e. n = 47) were used compared to the number of events occurred (i.e. 'response' or 'non-response'). Based on clinical relevance and supported by a data driven approach, only the most contributing prognostic indicators could be included in the multivariable logistic regression models for internal validation, which might lead to missing weaker prognostic factors. Moreover, 'confounding by indication' might have been introduced due to the observational design used. As the amount of potential predictive indicators was high, we were not able to add interaction terms to our models, which might have led to too optimistic (although we corrected for this optimism[14,15,32,42,43,81]) and less accurate models. Fifth, and related to the previous point, a classical multivariable logistic regression was chosen to develop and validate the models, as it produces relatively stable predictions and in relatively small datasets in particular[82], and limitations of this method for clinical practice are known. Bayesian network methodology could overcome these limitations as well as the previously mentioned weakness of the high amount of potential predictive indicators compared to the number of events occurred. The method allows for making predictions at various times during a health care process, each time using all the available information of the patient concerned[83]. However, it is currently unknown whether such models lead to better validity and more research is needed to determine the usefulness in clinical practice.

Conclusion and implications for clinical practice

Based on pre-consultation patient-reported characteristics and treatment outcomes different prognostic profiles were identified that may contribute to triage of CLBP patients to the right surgical or non-surgical specialist for consultation. The 'non-response' profile for elective lumbar spine surgery performed remarkably well. If successful, based on their patient-reported profile, these patients could be triaged to a non-surgical specialist and unnecessary and unhelpful surgeries could be avoided. In future when the prognostic patient-reported profiles remain stable, the NDT-CLBP could enhance timely triage patient to the right clinician and contributes to decision-making between clinician and patient. The profiles support improvement of both surgical and conservative treatment outcomes that ultimately results in a more efficient use of healthcare resources.

Supporting information

S1 Table. Indicators and coding.
(PDF)

S2 Table. Selected indicators.
(PDF)

S3 Table. Complete overview of results per indicator.
(PDF)

S1 Checklist. Completed STROBE checklist cohort studies.
(PDF)

Acknowledgments

The authors thank Jolanda Rubrech for her administrative support and Frank Laumen for managing the institution's spine outcomes registry.

Author Contributions

Conceptualization: Miranda L. van Hooff, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Data curation: Miranda L. van Hooff, Johanna M. van Dongen, Marinus de Kleuver.

Formal analysis: Miranda L. van Hooff.

Funding acquisition: Miranda L. van Hooff, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Investigation: Miranda L. van Hooff, Johanna M. van Dongen, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Methodology: Miranda L. van Hooff, Johanna M. van Dongen, Veerle M. Coupé, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Project administration: Miranda L. van Hooff, Marinus de Kleuver.

Resources: Miranda L. van Hooff, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Software: Miranda L. van Hooff, Johanna M. van Dongen.

Supervision: Miranda L. van Hooff, Veerle M. Coupé, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Validation: Miranda L. van Hooff, Johanna M. van Dongen, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Visualization: Miranda L. van Hooff, Johanna M. van Dongen, Raymond W. J. G. Ostelo, Marinus de Kleuver.

Writing – original draft: Miranda L. van Hooff.

Writing – review & editing: Miranda L. van Hooff, Johanna M. van Dongen, Veerle M. Coupé, Maarten Spruit, Raymond W. J. G. Ostelo, Marinus de Kleuver.

References

1. GBD, Global Burden of Disease Study 2013 Collaborators, Vos T, Barber RM, Bell B, Bertozzi-Villa A. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic anlysis for the Global Burden of Disease Study 2013. The Lancet 2015; 386: 743–800.
2. Luo X, Pietrobon R, Sun SX, Liu GG, Hey L. Estimates and patterns of direct health care expenditures among individuals with back pain in the United States. Spine (Phila Pa 1976) 2004; 29: 79–86. https://doi.org/10.1097/01.BRS.0000105527.13866.0F PMID: 14699281
3. Lambeek LC, van Tulder MW, Swinkels IC, Koppes LL, Anema JR, van Mechelen W.The trend in total cost of back pain in The Netherlands in the period 2002 to 2007. Spine (Phila Pa 1976) 2011; 36: 1050–1058. https://doi.org/10.1097/BRS.0b013e3181e70488 PMID: 21150697
4. Frymoyer JW.Predicting disability from low back pain. Clin Orthop Relat Res 1992;101–109.

5. Henschke N, Kuijpers T, Rubinstein SM, van Middelkoop M, Ostelo R, Verhagen A et al. Trends over time in the size and quality of randomised controlled trials of interventions for chronic low-back pain. Eur Spine J 2012; 21: 375–381. https://doi.org/10.1007/s00586-011-2023-z PMID: 22037844
6. Atlas SJ, Deyo RA. Evaluating and managing acute low back pain in the primary care setting. J Gen Intern Med 2001; 16: 120–131. jgi91141 [pii]. https://doi.org/10.1111/j.1525-1497.2001.91141.x PMID: 11251764
7. Hestbaek L, Leboeuf-Yde C, Manniche C. Low back pain: what is the long-term course? A review of studies of general patient populations. Eur Spine J 2003; 12: 149–165. https://doi.org/10.1007/s00586-002-0508-5 PMID: 12709853
8. Costa LC, Maher CG, McAuley JH, Hancock MJ, Herbert RD, Refshauge KM, Henschke N. Prognosis for patients with chronic low back pain: inception cohort study. BMJ 2009; 339: b3829. https://doi.org/10.1136/bmj.b3829 PMID: 19808766
9. Fairbank J, Gwilym SE, France JC, Daffner SD, Dettori J, Hermsmeyer J, Andersson G. The role of classification of chronic low back pain. Spine (Phila Pa 1976) 2011; 36: S19–S42. https://doi.org/10.1097/BRS.0b013e31822ef72c; 00007632-201110011-00003 [pii]. PMID: 21952188
10. Jacobs WC, Rubinstein SM, Koes B, van Tulder MW, Peul WC. Evidence for surgery in degenerative lumbar spine disorders. Best Pract Res Clin Rheumatol 2013; 27: 673–684. S1521-6942(13)00073-9 [pii]; https://doi.org/10.1016/j.berh.2013.09.009 PMID: 24315148
11. Kamper SJ, Apeldoorn AT, Chiarotto A, Smeets RJ, Ostelo RW, Guzman J, van Tulder MW. Multidisciplinary biopsychosocial rehabilitation for chronic low back pain: Cochrane systematic review and meta-analysis. BMJ 2015; 350: h444. https://doi.org/10.1136/bmj.h444 PMID: 25694111
12. Kamper SJ, Maher CG, Hancock MJ, Koes BW, Croft PR, Hay E. Treatment-based subgroups of low back pain: a guide to appraisal of research studies and a summary of current evidence. Best Pract Res Clin Rheumatol 2010; 24: 181–191. S1521-6942(09)00126-0 [pii]; https://doi.org/10.1016/j.berh.2009.11.003 PMID: 20227640
13. Fourney DR, Andersson G, Arnold PM, Dettori J, Cahana A, Fehlings MG et al. Chronic low back pain: a heterogeneous condition with challenges for an evidence-based approach. Spine (Phila Pa 1976) 2011; 36: S1–S9. https://doi.org/10.1097/BRS.0b013e31822f0a0d; 00007632-201110011-00001 [pii]. PMID: 21952181
14. Altman DG, Vergouwe Y, Royston P, Moons KG. Prognosis and prognostic research: validating a prognostic model. BMJ 2009; 338: b605. https://doi.org/10.1136/bmj.b605 PMID: 19477892
15. Moons KG, Royston P, Vergouwe Y, Grobbee DE, Altman DG. Prognosis and prognostic research: what, why, and how? BMJ 2009; 338: b375. https://doi.org/10.1136/bmj.b375 PMID: 19237405
16. Airaksinen O, Brox JI, Cedraschi C, Hildebrandt J, Klaber-Moffett J, Kovacs F, Mannion AF, Reis S, Staal JB, Ursin H, Zanoli G. Chapter 4. European guidelines for the management of chronic nonspecific low back pain. Eur Spine J 2006; 15 Suppl 2: S192–S300. https://doi.org/10.1007/s00586-006-1072-1 PMID: 16550448
17. Chou R, Loeser JD, Owens DK, Rosenquist RW, Atlas SJ, Baisden J et al. Interventional therapies, surgery, and interdisciplinary rehabilitation for low back pain: an evidence-based clinical practice guideline from the American Pain Society. Spine (Phila Pa 1976) 2009; 34: 1066–1077. https://doi.org/10.1097/BRS.0b013e3181a1390d PMID: 19363457
18. NICE, National Institute for Health and Clinical Excellence, National Collaborating Centre for Primary Care. Low Back Pain. Early management of persistent non-specific low back pain. NICE clinical guideline 88. 2009
19. Bederman SS. Predicting prognosis in sick-listed low back pain patients: sneaking a peak inside the black box. Spine J 2010; 10: 728–730. S1529-9430(10)00382-7 [pii]; https://doi.org/10.1016/j.spinee.2010.05.008 PMID: 20650411
20. Deyo RA, Dworkin SF, Amtmann D, Andersson G, Borenstein D, Carragee E et al. Report of the NIH Task Force on research standards for chronic low back pain. Phys Ther 2015; 95: e1–e18. 95/2/e1 [pii]; https://doi.org/10.2522/ptj.2015.95.2.e1 PMID: 25639530
21. van Hooff ML, van Loon J, van Limbeek J, de Kleuver M. The Nijmegen decision tool for chronic low back pain. Development of a clinical decision tool for secondary or tertiary spine care specialists. PLoS One 2014; 9: e104226. https://doi.org/10.1371/journal.pone.0104226; PONE-D-14-13335 [pii]. PMID: 25133645
22. Stromqvist B, Fritzell P, Hagg O, Jonsson B, Sanden B. Swespine: the Swedish spine register: the 2012 report. Eur Spine J 2013; 22: 953–974. https://doi.org/10.1007/s00586-013-2758-9 PMID: 23575657
23. Hemingway H, Croft P, Perel P, Hayden JA, Abrams K, Timmis A et al. Prognosis research strategy (PROGRESS) 1: a framework for researching clinical outcomes. BMJ 2013; 346: e5595. https://doi.org/10.1136/bmj.e5595 PMID: 23386360

24. Collins GS, Reitsma JB, Altman DG, Moons KG. Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD): the TRIPOD statement. Ann Intern Med 2015; 162: 55–63. 2088549 [pii]; https://doi.org/10.7326/M14-0697 PMID: 25560714

25. van Hooff ML, van der Merwe JD, O'Dowd J, Pavlov PW, Spruit M, de Kleuver M, van Limbeek J. Daily functioning and self-management in patients with chronic low back pain after an intensive cognitive behavioral programme for pain management. Eur Spine J 2010; 19: 1517–1526. https://doi.org/10.1007/s00586-010-1435-5 PMID: 20506027

26. PROQOLID. Patient-Reported Outcome and Quality of Life Instruments Database—Oswestry Disability Index (ODI). 2014

27. van Hooff ML, Spruit M, Fairbank JC, van Limbeek J, Jacobs WC. The Oswestry Disability Index (version 2.1a): validation of a Dutch language version. Spine (Phila Pa 1976) 2015; 40: E83–E90. https://doi.org/10.1097/BRS.0000000000000683; 00007632-201501150-00014 [pii]. PMID: 25575092

28. Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine (Phila Pa 1976) 2000; 25: 2940–2952.

29. van Hooff ML, Spruit M, O'Dowd JK, van LW, Fairbank JC, van LJ (2014) Predictive factors for successful clinical outcome 1 year after an intensive combined physical and psychological programme for chronic low back pain. Eur Spine J 23: 102–112. https://doi.org/10.1007/s00586-013-2844-z PMID: 23771553

30. van Hooff ML, Mannion AF, Staub LP, Ostelo RWJG, Fairbank JCT (2016) Determination of the Oswestry Disability Index score equivalent to a "satisfactory symptom state" in patients undergoing surgery for degenerative disorders of the lumbar spine. A Spine Tango registry-based study. Spine J. 2016.

31. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. Physiotherapy 1980; 66: 271–273. PMID: 6450426

32. Harrell F. E. Jr. Regression Modeling Strategies.With applications to linear models, logistic and ordinal regression and survival analysis. New York, NY: Springer International Publishing Switzerland. 2nd edition;2015.

33. Tabachnik BG, Fidell LS. Principal Components and Factor Analysis. In: Using Multivariate Statistics. Harlow, Essex: Pearson Education Limited. 6th edition;2014.

34. Athiviraham A, Wali ZA, Yen D. Predictive factors influencing clinical outcome with operative management of lumbar spinal stenosis. Spine J 2011; 11: 613–617. S1529-9430(11)00187-2 [pii]; https://doi.org/10.1016/j.spinee.2011.03.008 PMID: 21482198

35. Bekelis K, Desai A, Bakhoum SF, Missios S. A predictive model of complications after spine surgery: the National Surgical Quality Improvement Program (NSQIP) 2005–2010. Spine J 2014; 14: 1247–1255. S1529-9430(13)01456-3 [pii]; https://doi.org/10.1016/j.spinee.2013.08.009 PMID: 24211097

36. Planchard RF, Higgins DM, Mallory GW, Puffer RC, Jacob JT, Curry TB, et al. The Impact of Obesity on Perioperative Resource Utilization after Elective Spine Surgery for Degenerative Disease. Global Spine J 2015; 5: 287–293. https://doi.org/10.1055/s-0035-1546819; 1400131 [pii]. PMID: 26225277

37. Carreon LY, Glassman SD, Djurasovic M, Dimar JR, Johnson JR, Puno RM et al. Are preoperative health-related quality of life scores predictive of clinical outcomes after lumbar fusion? Spine (Phila Pa 1976) 2009; 34: 725–730. https://doi.org/10.1097/BRS.0b013e318198cae4; 00007632-200904010-00016 [pii]. PMID: 19333106

38. Soriano JC, Revuelta SM, Fuente FM, Diaz CI, Urena MP, Meneses DR. Predictors of outcome after decompressive lumbar surgery and instrumented posterolateral fusion. Eur Spine J 2010; 19: 1841–8. https://doi.org/10.1007/s00586-010-1284-2 PMID: 20135333

39. Sanden B, Forsth P, Michaelsson K. Smokers show less improvement than nonsmokers two years after surgery for lumbar spinal stenosis: a study of 4555 patients from the Swedish spine register. Spine (Phila Pa 1976) 2011; 36: 1059–1064. https://doi.org/10.1097/BRS.0b013e3181e92b36 PMID: 21224770

40. Pearson A, Lurie J, Tosteson T, Zhao W, Abdu W, Weinstein JN. Who should have surgery for spinal stenosis? Treatment effect predictors in SPORT. Spine (Phila Pa 1976) 2012; 37: 1791–1802. https://doi.org/10.1097/BRS.0b013e3182634b04; 00007632-201210010-00002 [pii]. PMID: 23018805

41. Nerland US, Jakola AS, Giannadakis C, Solheim O, Weber C, Nygaard OP et al. The Risk of Getting Worse: Predictors of Deterioration After Decompressive Surgery for Lumbar Spinal Stenosis: A Multicenter Observational Study. World Neurosurg 2015; 84: 1095–1102. S1878-8750(15)00652-X [pii]; https://doi.org/10.1016/j.wneu.2015.05.055 PMID: 26049114

42. Moons KG, Altman DG, Vergouwe Y, Royston P. Prognosis and prognostic research: application and impact of prognostic models in clinical practice. BMJ 2009; 338: b606. https://doi.org/10.1136/bmj.b606 PMID: 19502216

43. Royston P, Moons KG, Altman DG, Vergouwe Y. Prognosis and prognostic research: Developing a prognostic model. BMJ 2009; 338: b604. https://doi.org/10.1136/bmj.b604 PMID: 19336487

44. Vergouwe Y, Steyerberg EW, Eijkemans MJ, Habbema JD. Validity of prognostic models: when is a model clinically useful? Semin Urol Oncol 2002; 20: 96–107. S1081094302500267 [pii]. PMID: 12012295

45. LaCaille RA, DeBerard MS, Masters KS, Colledge AL, Bacon W. Presurgical biopsychosocial factors predict multidimensional patient: outcomes of interbody cage lumbar fusion. Spine J 2005; 5: 71–78. S1529-9430(04)00711-9 [pii]; https://doi.org/10.1016/j.spinee.2004.08.004 PMID: 15653087

46. Trief PM, Ploutz-Snyder R, Fredrickson BE. Emotional health predicts pain and function after fusion: a prospective multicenter study. Spine (Phila Pa 1976) 2006; 31: 823–830. https://doi.org/10.1097/01.brs.0000206362.03950.5b; 00007632-200604010-00016 [pii]. PMID: 16582857

47. Van Der Hulst M, Vollenbroek-Hutten MM, Groothuis-Oudshoorn KG, Hermens HJ. Multidisciplinary rehabilitation treatment of patients with chronic low back pain: a prognostic model for its outcome. Clin J Pain 2008; 24: 421–430. https://doi.org/10.1097/AJP.0b013e31816719f5; 00002508-200806000-00009 [pii]. PMID: 18496307

48. Smeets RJ, Beelen S, Goossens ME, Schouten EG, Knottnerus JA, Vlaeyen JW (2008) Treatment expectancy and credibility are associated with the outcome of both physical and cognitive-behavioral treatment in chronic low back pain. Clin J Pain 24: 305–315. https://doi.org/10.1097/AJP.0b013e318164aa75; 00002508-200805000-00005 [pii]. PMID: 18427229

49. Abbott AD, Tyni-Lenne R, Hedlund R. Leg pain and psychological variables predict outcome 2–3 years after lumbar fusion surgery. Eur Spine J 2011; 20: 1626–1634. https://doi.org/10.1007/s00586-011-1709-6 PMID: 21311916

50. Verkerk K, Luijsterburg PA, Heymans MW, Ronchetti I, Miedema HS, Koes BW et al. Prognostic factors and course for successful clinical outcome quality of life and patients' perceived effect after a cognitive behavior therapy for chronic non-specific low back pain: A 12-months prospective study. Man Ther 2015; 20: 96–102. S1356-689X(14)00129-5 [pii]; https://doi.org/10.1016/j.math.2014.07.003 PMID: 25107827

51. Samartzis D, Borthakur A, Belfer I, Bow C, Lotz JC, Wang HQ et al. Novel diagnostic and prognostic methods for disc degeneration and low back pain. Spine J 2015; 15: 1919–1932. S1529-9430(14)01448-X [pii]; https://doi.org/10.1016/j.spinee.2014.09.010 PMID: 26303178

52. Block AR, Ohnmeiss DD, Guyer RD, Rashbaum RF, Hochschuler SH. The use of presurgical psychological screening to predict the outcome of spine surgery. Spine J 2001; 1: 274–282. S1529-9430(01)00054-7 [pii]. PMID: 14588332

53. Havakeshian S, Mannion AF. Negative beliefs and psychological disturbance in spine surgery patients: a cause or consequence of a poor treatment outcome? Eur Spine J 2013; 22: 2827–2835. https://doi.org/10.1007/s00586-013-2822-5 PMID: 23695229

54. Chotai S, Sivaganesan A, Parker SL, McGirt MJ, Devin CJ. Patient-Specific Factors Associated With Dissatisfaction After Elective Surgery for Degenerative Spine Diseases. Neurosurgery 2015; 77: 157–163. https://doi.org/10.1227/NEU.0000000000000768 PMID: 25910085

55. Lee MJ, Cizik AM, Hamilton D, Chapman JR. Predicting medical complications after spine surgery: a validated model using a prospective surgical registry. Spine J 2014; 14: 291–299. S1529-9430(13)01648-3 [pii]; https://doi.org/10.1016/j.spinee.2013.10.043 PMID: 24239799

56. McGirt MJ, Sivaganesan A, Asher AL, Devin CJ. Prediction model for outcome after low-back surgery: individualized likelihood of complication, hospital readmission, return to work, and 12-month improvement in functional disability. Neurosurg Focus 2015; 39: E13. https://doi.org/10.3171/2015.8.FOCUS15338 PMID: 26621411

57. Johansson AC, Ohrvik J, Soderlund A. Associations among pain, disability and psychosocial factors and the predictive value of expectations on returning to work in patients who undergo lumbar disc surgery. Eur Spine J 2016; 25: 296–303. https://doi.org/10.1007/s00586-015-3820-6 PMID: 25716659

58. Zehnder P, Aghayev E, Fekete TF, Haschtmann D, Pigott T, Mannion AF. Influence of previous surgery on patient-rated outcome after surgery for degenerative disorders of the lumbar spine. Eur Spine J 2016; https://doi.org/10.1007/s00586-016-4383-x PMID: 26801193

59. Hall H, McIntosh G, Boyle C. Effectiveness of a low back pain classification system. Spine J 2009; 9: 648–657. S1529-9430(09)00165-X [pii]; https://doi.org/10.1016/j.spinee.2009.04.017 PMID: 19501026

60. Denteneer L, Van DU, De HW, Truijen S, Stassijns G. Identification of Preliminary Prognostic Indicators for Back Rehabilitation in Patients With Nonspecific Chronic Low Back Pain: A Retrospective Cohort Study. Spine (Phila Pa 1976) 2016; 41: 522–529. https://doi.org/10.1097/BRS.0000000000001262 PMID: 26536437

61. Chapin L, Ward K, Ryken T (2015) Preoperative Depression, Smoking, and Employment Status are Significant Factors in Patient Satisfaction After Lumbar Spine Surgery. J Spinal Disord Tech. https://doi.org/10.1097/BSD.0000000000000331 PMID: 28632560

62. Mannion AF, Junge A, Elfering A, Dvorak J, Porchet F, Grob D. Great expectations: really the novel predictor of outcome after spinal surgery? Spine (Phila Pa 1976) 2009; 34: 1590–1599. https://doi.org/10.1097/BRS.0b013e31819fcd52 PMID: 19521272

63. Soroceanu A, Ching A, Abdu W, McGuire K. Relationship between preoperative expectations, satisfaction, and functional outcomes in patients undergoing lumbar and cervical spine surgery: a multicenter study. Spine (Phila Pa 1976)2012; 37: E103–E108. https://doi.org/10.1097/BRS.0b013e3182245c1f PMID: 21629159

64. Ellis DJ, Mallozzi SS, Mathews JE, Moss IL, Ouellet JA, Jarzem P, Weber MH. The relationship between preoperative expectations and the short-term postoperative satisfaction and functional outcome in lumbar spine surgery. A systemtic review. Global Spine J 2015; 5: 436–452. https://doi.org/10.1055/s-0035-1551650 PMID: 26430599

65. Premkumar A, Godfrey W, Gottschalk MB, Boden SD. Red Flags for Low Back Pain Are Not Always Really Red: A Prospective Evaluation of the Clinical Utility of Commonly Used Screening Questions for Low Back Pain. J Bone Joint Surg Am 2018; 100: 368–374. https://doi.org/10.2106/JBJS.17.00134; 00004623-201803070-00003 [pii]. PMID: 29509613

66. Briggs T. Getting it right the first time. Improving the quality of orthopaedic care within the National Health Service in England. 2015.

67. Athiviraham A, Wali ZA, Yen D. Predictive factors influencing clinical outcome with operative management of lumbar spinal stenosis. Spine J 2011; 11: 613–617. S1529-9430(11)00187-2 [pii]; https://doi.org/10.1016/j.spinee.2011.03.008 PMID: 21482198

68. Sherry B, Jefferds ME, Grummer-Strawn LM. Accuracy of adolescent self-report of height and weight in assessing overweight status: a literature review. Arch Pediatr Adolesc Med 2007; 161: 1154–1161. 161/12/1154 [pii]; https://doi.org/10.1001/archpedi.161.12.1154 PMID: 18056560

69. Connor GS, Schofield-Hurwitz S, Hardt J, Levasseur G, Tremblay M. The accuracy of self-reported smoking: a systematic review of the relationship between self-reported and cotinine-assessed smoking status. Nicotine Tob Res 2009; 11: 12–24. ntn010 [pii]; https://doi.org/10.1093/ntr/ntn010 PMID: 19246437

70. Jerome GJ, Dalcin A, Coughlin JW, Fitzpatrick S, Wang NY, Durkin N et al. Longitudinal accuracy of web-based self-reported weights: results from the Hopkins POWER Trial. J Med Internet Res 2014; 16: e173. v16i7e173 [pii]; https://doi.org/10.2196/jmir.3332 PMID: 25042773

71. Stelmach R, Fernandes FL, Carvalho-Pinto RM, Athanazio RA, Rached SZ, Prado GF et al. Comparison between objective measures of smoking and self-reported smoking status in patients with asthma or COPD: are our patients telling us the truth? J Bras Pneumol 2015; 41: 124–132. https://doi.org/10.1590/S1806-37132015000004526 PMID: 25972966

72. Clement RC, Welander A, Stowell C, Cha TD, Chen JL, Davies M et al. A proposed set of metrics for standardized outcome reporting in the management of low back pain. Acta Orthop 2015; 86: 523–533. https://doi.org/10.3109/17453674.2015.1036696 PMID: 25828191

73. Okoro T, Sell P. The prediction of outcome in somatised patients undergoing elective lumbar surgery. J Bone Joint Surg Br 2009; 91: 517–521. 91-B/4/517 [pii]; https://doi.org/10.1302/0301-620X.91B4.21861 PMID: 19336814

74. de Vet HC, Foumani M, Scholten MA, Jacobs WC, Stiggelbout AM, Knol DL et al. Minimally important change values of a measurement instrument depend more on baseline values than on the type of intervention. J Clin Epidemiol 2015; 68: 518–524. S0895-4356(14)00452-1 [pii]; https://doi.org/10.1016/j.jclinepi.2014.07.008 PMID: 25544741

75. Ostelo RW, Deyo RA, Stratford P, Waddell G, Croft P, Von KM, Bouter LM, de Vet HC. Interpreting change scores for pain and functional status in low back pain: towards international consensus regarding minimal important change. Spine (Phila Pa 1976) 2008; 33: 90–94. https://doi.org/10.1097/BRS.0b013e31815e3a10; 00007632-200801010-00015 [pii]. PMID: 18165753

76. Adams ST, Leveson SH. Clinical prediction rules. BMJ 2012; 344: d8312. https://doi.org/10.1136/bmj.d8312 PMID: 22250218

77. Haskins R, Osmotherly PG, Rivett DA. Validation and impact analysis of prognostic clinical prediction rules for low back pain is needed: a systematic review. J Clin Epidemiol 2015; 68: 821–832. S0895-4356(15)00089-X [pii]; https://doi.org/10.1016/j.jclinepi.2015.02.003 PMID: 25804336

78. Chapman JR, Norvell DC, Hermsmeyer JT, Bransford RJ, DeVine J, McGirt MJ, Lee MJ. Evaluating common outcomes for measuring treatment success for chronic low back pain. Spine (Phila Pa 1976) 2011; 36: S54–S68. https://doi.org/10.1097/BRS.0b013e31822ef74d; 00007632-201110011-00005 [pii]. PMID: 21952190

79. McCormick JD, Werner BC, Shimer AL. Patient-reported outcome measures in spine surgery. J Am Acad Orthop Surg 2013; 21: 99–107. 21/2/99 [pii]; https://doi.org/10.5435/JAAOS-21-02-99 PMID: 23378373

80. Chiarotto A, Deyo RA, Terwee CB, Boers M, Buchbinder R, Corbin TP et al. Core outcome domains for clinical trials in non-specific low back pain. Eur Spine J2015; 24: 1127–1142. https://doi.org/10.1007/s00586-015-3892-3 PMID: 25841358

81. Pavlou M, Ambler G, Seaman SR, Guttmann O, Elliott P, King M, Omar RZ. How to develop a more accurate risk prediction model when there are few events. BMJ 2015; 351: h3868. https://doi.org/10.1136/bmj.h3868 PMID: 26264962

82. van der Ploeg T, Austin PC, Steyerberg EW. Modern modelling techniques are data hungry: a simulation study for predicting dichotomous endpoints. BMC Med Res Methodol 2014; 14: 137. 1471-2288-14-137 [pii]; https://doi.org/10.1186/1471-2288-14-137 PMID: 25532820

83. Verduijn M, Rosseel PM, Peek N, de JE, de Mol BA. Prognostic Bayesian networks II: an application in the domain of cardiac surgery. J Biomed Inform 2007; 40: 619–630. S1532-0464(07)00063-9 [pii]; https://doi.org/10.1016/j.jbi.2007.07.004 PMID: 17709302