MEDINFO 2019: Health and Wellbeing e-Networks for All
L. Ohno-Machado and B. Séroussi (Eds.)

doi:10.3233/SHTI190285

Improving Adherence to Clinical Pathways Through Natural Language Processing on Electronic Medical Records

Noa P. Cruz[a], Lea Canales[a], Javier García Muñoz[b], Bernardino Pérez[b], Ignacio Arnott[c]

[a] *Medsavana S.L., Madrid, Spain*
[b] *Servicio de Salud de Castilla-La Mancha, Castilla-La Mancha, Spain*
[c] *Accenture, Madrid, Spain*

Abstract

This paper presents a pioneering and practical experience in the development and implementation of a clinical decision support system (CDSS) based on natural language processing (NLP) and artificial intelligence (AI) techniques. Our CDSS notifies primary care physicians in real time about recommendations regarding the healthcare process. This is, to the best of our knowledge, the first real-time CDSS implemented in the Spanish National Health System. We achieved adherence rate improvements in eight out of 18 practices. Moreover, the provider's feedback was very positive, describing the solution as fast, useful, and unintrusive. Our CDSS reduced clinical variability and revealed the usefulness of NLP and AI techniques for the evaluation and improvement of health care.

Keywords:

Critical pathways; decision support systems, clinical; natural language processing

Introduction

A clinical pathway is a structured multidisciplinary care plan tool built on evidence-based medicine, which states essential goals and key elements in the management of a well-defined group of patients [1]. Although there is no single and widely accepted definition of a clinical pathway, the aim of these tools is to improve quality of care, reduce risks, improve patient satisfaction, and promote efficient use of healthcare resources [2].

The benefits of implementing clinical pathways in routine clinical practice are well documented and include increased hospital efficiency [3; 4], decreased length of hospital stay [5], and lowered costs [6]. In order to obtain these benefits, implementations of clinical pathways should comply with a minimum set of basic principles [7]; the lack of implementation of these principles by healthcare professionals negatively impacts patient care [8-10].

Computerized approaches are considered promising tools for increasing adherence to clinical pathways [11]. For example, adherence to clinical guidelines for acute decompensated heart failure [12] and glucose regulation in an intensive care unit [13] were successfully improved using computerized pathways in user-friendly formats. Other studies implemented a CDSS that sends computerized clinical reminders to professionals [14; 15]. Yet another evaluated adherence to acute bacterial rhinosinusitis guidelines in three phases: 1) inform each participant about personal adherence rate, 2) perform an educational intervention about clinical pathways, and 3) introduce a CDSS [16]. However, a study that investigated whether the redesign of a CDSS leads to a more appropriate prescription of antimicrobials was not able to detect the expected improvement [17]. Obviously, many factors, such as poor usability or lack of follow-up, can have a negative impact on the desired outcome. A successful CDSS implementation needs to detect and eliminate these factors.

Clinical pathway adherence can be measured from the patients' perspective (adherence to treatments) [18-20] or the professionals' perspective (adherence to clinical pathways) [21-24]. However, what these studies have in common is that the adherence was evaluated using questionnaires, a process which requires significant amounts of time and resources. A thoughtful implementation of healthcare information technology (HIT) can greatly improve the efficiency of clinical pathways [25].

Inspired by the discussion about the use of clinical practice guidelines in primary care in Spain [26], we present a real-time CDSS to improve adherence rates to clinical pathways. The real-time CDSS proposed was developed by Accenture[1] and integrates Savana's[2] EHRead Technology which automatically extracts valuable medical information from unstructured free text information contained in electronic health records (EHRs). Our results demonstrate improvements in clinical adherence due to the use of the real-time CDSS. The real-time CDSS reduces the variability of healthcare and establishes a method for measuring adherence. It also helps to understand the difficulties in implementing clinical pathways and how to overcome them.

Methods

Savana System

Savana [27] was founded in 2014 with the goal of using AI to improve the quality of health services. Savana has developed EHRead, a powerful technology that applies the latest NLP, machine learning and deep learning techniques to analyze the unstructured free text information written in millions of EHRs and automatically extract highly valuable medical information. The pipeline consists of different modules performing tasks such as sentence segmentation, tokenization, text normalization, acronym disambiguation, negation detection, and a multi-dimensional ranking scheme. To execute these tasks, the pipeline combines linguistic knowledge, statistical evidence and state-of-the-art continuous vector representations of words and documents in the clinical domain learned via shallow neural networks. The Savana Manager software is the first medical linguistic engine that applies this concept to the Spanish language, converting the

[1] https://www.accenture.com/
[2] https://www.savanamed.com/

valuable information contained in EHR free text into an interpretable and user-friendly format. A general overview of the CDSS interface is shown in Figure 1.

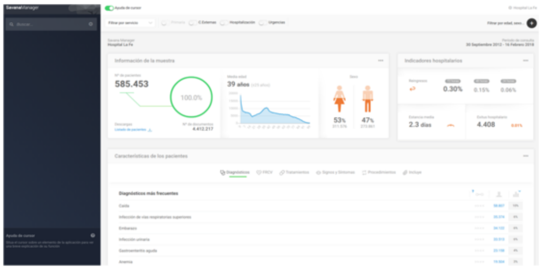

Figure 1 – Savana Manager Interface

Implementation and Evaluation Process

The real-time CDSS was implemented and evaluated in the primary care area of Castilla-La Mancha's Health Service (SESCAM)[3], serving a region in Spain with more than two million inhabitants. 24 healthcare centers with a total of 86 physicians (general practitioners and pediatricians) participated in this pioneering experience.

The CDSS proposed consists of a real-time tool developed by Accenture which continuously processes the notes taken by professionals during their medical consultation. This technology integrates Savana's EHRead Technology whose objective is to extract and identify the most important clinical information from EHRs. The CDSS warns professionals when the case meets a criteria for a recommendation.

In order to assess the ability of this CDSS to improve clinical pathway adherence, a well-defined methodology was carried out. This methodology consists of the following steps:

1. Translation of clinical pathways into rules by the Savana medical team. These rules define which clinical terms are relevant for each pathway and how they relate to each other.
2. With these rules and the information automatically extracted by Savana Manager, the professionals' adherence to the different clinical pathways is evaluated. To achieve this goal, a dataset of more than 2.5 million documents from emergency and primary care services, archived during a time period ranging from 01/01/2016 to 31/05/2017, was analyzed. We refer to this as the first measurement period.

   From this evaluation, those clinical pathways that had less than 90% compliance were translated into recommendations by our medical team. These recommendations were implemented in a real-time alert system in an attempt to improve adherence rates. Table 1 shows the 18 recommendations defined and their degree of compliance in clinical practice in the first measurement period.
3. Once the proposed CDSS was implemented, an additional adherence evaluation was performed. In this second measurement period, a dataset of more than 345,000 clinical documents, archived during a time period ranging from 27/11/2017 to 31/12/2017, was analyzed in order to assess the benefits of our CDSS.

To quantify the changes in adherence rates to clinical pathways between the first and second measurement periods, we compared the number of documents in which the patients' cases followed the correct clinical pathway before implementation with the number correct after the implementation.

We tested whether the difference between the two proportions (adherence rates before and after implementation) was significant using a two-proportion z-test, which is calculated as:

$$Z = \frac{P_2 - P_1}{\sqrt{P^{-} \cdot (1 - P^{-}) \cdot \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where P^{-} is the proportion of successes over all of our samples combined:

$$P^{-} = \frac{n_1 \cdot P_1 + n_2 \cdot P_2}{n_1 + n_2}$$

P_1 and P_2 are the adherence rates of samples 1 (before implementation) and 2 (after implementation); n_1 and n_2 are the respective sample sizes.

The null hypothesis H_0 is that there is no improvement in the adherence after implementation:

$$H_0: P_2 <= P_1$$
$$H_1: P_2 > P_1$$

The p-value is equal to 1−Z, assuming the standard normal cumulative distribution. H_0 is rejected if the p-value is lower than 0.05.

Results

Adherence rates to clinical pathways improved in eight out of 18 recommendations when our real-time CDSS was employed, achieving 100% compliance in some cases (Table 2, Figure 2). The improvement was statistically significant in three cases ($p < 0.05$). Considering that this was a preliminary study, these results are promising. The greatest increase in degree of improvement (76%) occurred in recommendation #10 ("SSRIs should not be prescribed to patients with chronic lower back pain unless they are also suffering from depression"). This means that before implementation of our CDSS, professionals often prescribed the use of SSRIs in cases for which it was not clinically recommended; afterwards, the number of these cases decreased dramatically.

The remaining ten recommendations could not be evaluated due to one of two main reasons: 1) these were recommendations for referrals to another service or requests for evidence which require a long period of time to check whether the referral or follow-up in question was requested, or 2) the volume of data was insufficient to make an analysis and draw conclusions. Although one month is a short period of time to evaluate the impact of a CDSS, subsequent evaluations will enrich these results. Importantly, this preliminary assessment made it possible to come up with an initial measure of the CDSS's effectiveness.

[3] See http://sescam.castillalamancha.es/

Table 1– Set of recommendations implemented and their degree of compliance before CDSS implementation

	Recommendation	Degree of compliance (%)
Osteoarthritis of the Hip and Knee	1. Glucosamine and chondroitin sulphate should not be routinely given to patients with hip or knee OA, as there are no relevant clinical benefits	84
	2. The routine use of NSAIDs is not recommended in patients with OA of the hip or knee who have coexisting cardiovascular pathologies such as heart failure or ACS	88
Anxiety	3. Patients with post-traumatic stress disorder should be referred to the mental health team	83
	4. Patients with anxiety should be prescribed pregabalin rather than benzodiazepines due to improved tolerance, fewer side effects, and the possibility of long-term use	9
	5. Fluoxetine doses should not be divided due to a half-life of up to 72h	86
Headache	6. All patients over 50 with headache and temporal arthritis should be referred to a specialist	83
	7. Patients suffering from cluster headaches should be advised to avoid alcohol	2
Dyspepsia	8. Patients over 55 years old with dyspepsia should be referred for a gastroscopy	61
Lower Back Pain	9. Physiotherapy is the treatment of choice for acute lower back pain	42
	10. SSRIs should not be prescribed to patients with chronic lower back pain unless they are also suffering from depression	24
Heart Failure (HF)	11. The use of antialdosterones is recommended for all patients with NYHA stage II-IV HF and a LVEF of < 35%	75
	12. The follow-up for HF patients should include a chest X-ray at least once a year in order to evaluate the cardiothoracic ratio	71
Urinary Tract Infection (UTI)	13. Patients with prostatitis should have a urine sample sent for microscopy and culture	44
	14. Fosfomycin and co-amoxiclav should be avoided when treating UTIs in young men (14-45 years old)	82
	15. Pregnant women diagnosed with a UTI should have a urine sample sent for microscopy and culture	50
Heart Murmur	16. Patients with a heart murmur and a personal or family history of cardiac illness should be referred to a specialist	72
Osteoporosis	17. Calcium should not be routinely given to patients under 70 years old who are diagnosed with osteoporosis	68
	18. Pharmacological treatment (biphosphonates) should not be routinely given to patients over 80 years diagnosed with osteoporosis	84

OA=Osteoarthrosis; NSAID=Non-Steroid Anti-Inflammatory Drug; ACS=Acute Coronary Syndrome; SSRI=Selective Serotonin Reuptake Inhibiting Drug; NYHA=New York Heart Association; LVEF=Left Ventricular Ejection Fraction.

In order to evaluate how our CDSS affected physicians, we monitored the number of alerts/recommendations on a daily basis. In the second measurement period, a total of 534 recommendations were provided, which translated into 15.7 alerts per day. This means that, on average, each of the 86 physicians that participated in this experiment received 1.8 alerts per day. This shows that our real-time CDSS is non-intrusive and is therefore highly unlikely to produce alert fatigue.

Table 2 – Comparison of the degree of compliance with recommendations before and after the implementation of the CDSS

Rec #	Compliance % (Before)	Compliance % (After)	Improvement %
4	9	16	7 (p=0.145)
10	24	100	76* (p=0.01)
12	71	87	16* (p=0.01)
13	44	71	27 (p=0.053)
14	82	100	18 (p=0.108)
15	50	100	50* (p=0.013)
17	68	73	5 (p=0.314)
18	84	100	16 (p=0.096)

Statistically significant improvements (*t*-test, $p < 0.05$) are starred (*).
The term "before" refers to the first measurement period (01/01/2016 - 31/05/2017).
The term "after" refers to the second measurement period (27/11/2017 - 31/12/2017).
The period between 01/06/2017 and 26/11/2017 was used to extract the data provided by the healthcare centers and to train and configure the CDSS.

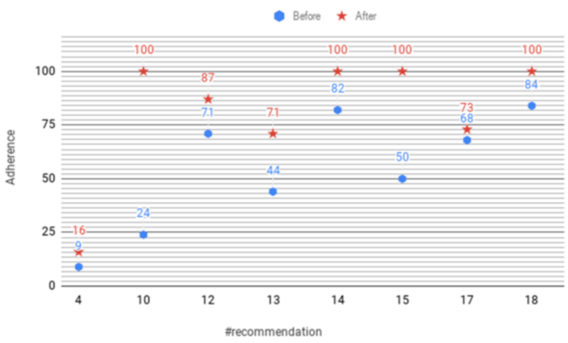

Figure 2 – Graphical representation of the improvement in adherence rates between the two measurement periods

Finally, a presidential session with our team and the participating physicians was carried out to directly obtain feedback from the users. The general response was very positive; the solution was described as fast, very useful and unintrusive, since it did not affect the dynamics of their work.

Discussion

The adoption of AI and big data in healthcare is increasing since numerous studies have shown that these techniques help to solve a variety of problems for patients, healthcare centers, and the healthcare industry in general. These new applications are more than just technological and analytical tools; they transform healthcare ecosystems by interactively connecting medical data, personalized medicine, and AI with clinical staff to improve patient care.

A new example of this ongoing transformation is the real-time CDSS presented in this paper. In fact, the results are very promising, although their preliminary nature means they must be interpreted with caution. An improvement in adherence rates was achieved in eight of the 18 established recommendations, this improvement being statistically significant in three of them. An important feature of our CDSS is its ability to adapt recommendations over time, thereby achieving proactive management of best practices.

One limitation of our project – indeed, any project working with EHRs – is EHR incompleteness. This can sometimes result in an insufficient amount of information for meaningful processing and measurement.

Our CDSS is currently in operation, and a more complete analysis will be provided in the near future. We will extend the project to the rest of the Healthcare Centers of Castilla-La Mancha and add recommendations for nurses. We will also add the capability to deactivate recommendations that achieve a degree of compliance of greater than 90%. Finally, we will enable professionals to add their own recommendations and follow their evolution in their adherence to clinical pathways.

Conclusions

This paper presents the first real-time CDSS based on NLP and AI techniques implemented in the Spanish National Health System. It allows measurement and improvement of the adherence of primary care physicians to the clinical pathways established by the Health Service. This CDSS helps professionals in their decision-making process and reduces the variability of clinical practice in the healthcare centers, having a very positive effect on overall quality of care.

Acknowledgements

We thank medical writer Ana Lopez-Ballesteros for her help in writing the paper.

References

[1] L. Kinsman, T. Rotter, E. James, P. Snow, and J. Willis, What is a clinical pathway? Development of a definition to inform the debate, *BMC Med* **8** (2010), 31.

[2] A.K. Lawal, T. Rotter, L. Kinsman, A. Machotta, U. Ronellenfitsch, S.D. Scott, D. Goodridge, C. Plishka, and G. Groot, What is a clinical pathway? Refinement of an operational definition to identify clinical pathway studies for a Cochrane systematic review, *BMC Med* **14** (2016), 35.

[3] J.M. Villar del Moral, V. Soria Aledo, A. Colina Alonso, B. Flores Pastor, M.T. Gutierrez Rodriguez, J. Ortega Serrano, P. Parra Hidalgo, and S. Ros Lopez, Clinical Pathway for Thyroidectomy, *Cir Esp* **93** (2015), 283-299.

[4] J.G. Yetzer, P. Pirgousis, Z. Li, and R. Fernandes, Clinical Pathway Implementation Improves Efficiency of Care in a Maxillofacial Head and Neck Surgery Unit, *J Oral Maxillofac Surg* **75** (2017), 190-196.

[5] S.D. Pearson, S.F. Kleefield, J.R. Soukop, E.F. Cook, and T.H. Lee, Critical pathways intervention to reduce length of hospital stay, *Am J Med* **110** (2001), 175-180.

[6] M.A. Bryan, A.D. Desai, L. Wilson, D.R. Wright, and R. Mangione-Smith, Association of Bronchiolitis Clinical Pathway Adherence With Length of Stay and Costs, *Pediatrics* **139** (2017).

[7] A.E.J. Ruiz López P, Ferrándiz Santos J., El diseño de la calidad: la gestión de vías clínicas en el contexto de planes de calidad, *JANO* **65** (2004), 75-80.

[8] J.J. Gomez-Doblas, [Implementation of clinical guidelines], *Rev Esp Cardiol* **59 Suppl 3** (2006), 29-35.

[9] M.D. Cabana, C.S. Rand, N.R. Powe, A.W. Wu, M.H. Wilson, P.A. Abboud, and H.R. Rubin, Why don't physicians follow clinical practice guidelines? A framework for improvement, *Jama* **282** (1999), 1458-1465.

[10] J. van de Klundert, P. Gorissen, and S. Zeemering, Measuring clinical pathway adherence, *J Biomed Inform* **43** (2010), 861-872.

[11] S. Ferrante, S. Bonacina, G. Pozzi, F. Pinciroli, and S. Marceglia, A Design Methodology for Medical Processes, *Applied clinical informatics* **7** (2016), 191-210.

[12] N.J. Gardetto, K. Greaney, L. Arai, A. Brenner, K.C. Carroll, N.M. Howerton, M. Lee, L. Pada, M. Tseng, and A.S. Maisel, Critical pathway for the management of acute heart failure at the Veterans Affairs San Diego Healthcare System: transforming performance measures into cardiac care, *Crit Pathw Cardiol* **7** (2008), 153-172.

[13] E. Rood, R.J. Bosman, J.I. van der Spoel, P. Taylor, and D.F. Zandstra, Use of a computerized guideline for glucose regulation in the intensive care unit improved both guideline adherence and glucose regulation, *J Am Med Inform Assoc* **12** (2005), 172-180.

[14] F.O. Kooij, T. Klok, B. Preckel, M.W. Hollmann, and J.E. Kal, The effect of requesting a reason for non-adherence to a guideline in a long running automated reminder system for PONV prophylaxis, *Applied clinical informatics* **8** (2017), 313-321.

[15] S.J. Wu, M. Lehto, Y. Yih, J.J. Saleem, and B.N. Doebbeling, Relationship of estimated resolution time and computerized clinical reminder adherence, *AMIA Annu Symp Proc* (2007), 334-338.

[16] K.L. Smith, D. Tran, and B.L. Westra, Sinusitis Treatment Guideline Adherence in the E-Visit Setting: A Performance Improvement Project, *Appl Clin Inform* **7** (2016), 299-307.

[17] M.T. Baysari, J. Del Gigante, M. Moran, I. Sandaradura, L. Li, K.L. Richardson, A. Sandhu, E.C. Lehnbom, J.I. Westbrook, and R.O. Day, Redesign of computerized decision support to improve antimicrobial prescribing. A controlled before-and-after study, *Appl Clin Inform* **8** (2017), 949-963.

[18] J. González-Bueno, M.D. Vega-Coca, A. Rodríguez-Pérez, M.D. Toscano-Guzmán, C. Pérez-Guerrero, and B. Santos-Ramos, Intervenciones para la mejora de la adherencia al tratamiento en pacientes pluripatológicos: resumen de revisiones sistemáticas, *Atención Primaria* **48** (2016), 121-130.

[19] L.d.l.Á. Martín Alfonso, J.A. Grau Ábalo, and A.D. Espinosa Brito, Marco conceptual para la evaluación y mejora de la adherencia a los tratamientos médicos en enfermedades crónicas %J Revista Cubana de Salud Pública, **40** (2014), 222-235.

[20] V.V.M.-H.G.G.J.G. Roales-Nieto, Aplicación de un programa de mejora de la adherencia en pacientes hipertensos debutantes, *Atención Primaria* **47** (2015), 83-89.

[21] M. Abd Rahman, R. Ahmad Zaki, R. Sarimin, M.I. Ariff, Z. Suli, M. Mahmud, K. Hong Bee, C. Anthonysamy, A. Abdul Rahim, B. Singh Gill, S. Rudra Deva, A.F.

Abdullah Sani, E.Z. Romli, I.M. Mohamed Ghazali, M.A. Mohd Yusof, N. Ahmad Lutfi, S.E. Shuib, N. Mohd Darus, R. Bakri, and Yahya, Adherence to Clinical Practice Guidelines (CPG) management of dengue infection in adults (revised 2nd edition), *PLoS One* **12** (2017), e0184559.

[22] N.S. Bauer, A.E. Carroll, C. Saha, and S.M. Downs, Computer Decision Support Changes Physician Practice But Not Knowledge Regarding Autism Spectrum Disorders, *Appl Clin Inform* **6** (2015), 454-465.

[23] M. Fragoso Marchante, A. Espinosa Brito, G. Álvarez Amador, I. González Morales, J. Bernal Muñoz, and M. Mosquera Fernández, Adherencia a las guías de prácticas clínicas sobre neumonía adquirida en la comunidad y su relación con la mortalidad: un problema sociomédico %J MediSur, **8** (2010), 49-56.

[24] A.F.H. I.S. Carballosa, A.M.H. Cardoso, J.J.N. López, and R.T. Peña., ADHERENCIAS A LAS GUÍAS DE BUENAS PRÁCTICAS CLÍNICAS DE ANGINA INESTABLE. SERVICIO DE CARDIOLOGÍA.CIENFUEGOS 2004, in, 2004.

[25] W. Dong and Z. Huang, A Method to Evaluate Critical Factors for Successful Implementation of Clinical Pathways, *Applied clinical informatics* **6** (2015), 650-668.

[26] J. Gene-Badia, P. Gallo, J. Cais, E. Sanchez, C. Carrion, L. Arroyo, and M. Aymerich, The use of clinical practice guidelines in primary care: professional mindlines and control mechanisms, *Gac Sanit* **30** (2016), 345-351.

[27] L.T. Espinosa-Anke, J.; Pardo, A.; Medrano, I.; Ureña, A.; Salcedo, I.; Saggion, H. , Savana: A Global Information Extraction and Terminology Expansion Framework in the Medical Domain *Procesamiento del Lenguaje Natural* **57** (2016), 23-30.

Address for correspondence

Noa P. Cruz, Medsavana S.L.

C/ Jiloca 4 - 5 Derecha, 28016 Madrid

+34-91 069 69 03 contact@noacruz.com