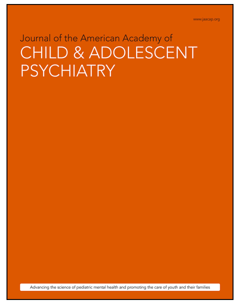
Journal Pre-proof



Clinical Decision Support Systems: An Innovative Approach to Enhancing Child and Adolescent Mental Health Services

Carolyn E. Clausen, MSc, Bennett L. Leventhal, MD, Øystein Nytrø, PhD, Roman Koposov, MD, PhD, Odd Sverre Westbye, MSc, Thomas Brox Røst, MSc, Victoria Bakken, MSc, Kaban Koochakpour, MSc, Ketil Thorvik, BA, Norbert Skokauskas, MD, PhD

PII: S0890-8567(20)31981-X

DOI: https://doi.org/10.1016/j.jaac.2020.09.018

Reference: JAAC 3245

To appear in: *Journal of the American Academy of Child & Adolescent Psychiatry*

Received Date: 16 June 2020

Revised Date: 7 September 2020

Accepted Date: 19 September 2020

Please cite this article as: Clausen CE, Leventhal BL, Nytrø Ø, Koposov R, Westbye OS, Røst TB, Bakken V, Koochakpour K, Thorvik K, Skokauskas N, Clinical Decision Support Systems: An Innovative Approach to Enhancing Child and Adolescent Mental Health Services, *Journal of the American Academy of Child & Adolescent Psychiatry* (2020), doi: https://doi.org/10.1016/j.jaac.2020.09.018.

Clinical Decision Support Systems: An Innovative Approach to Enhancing Child and Adolescent Mental Health Services
RH = Translations

Carolyn E. Clausen, MSc, Bennett L. Leventhal, MD, Øystein Nytrø, PhD, Roman Koposov, MD, PhD, Odd Sverre Westbye, MSc, Thomas Brox Røst, MSc, Victoria Bakken, MSc, Kaban Koochakpour, MSc, Ketil Thorvik, BA, Norbert Skokauskas, MD, PhD

Accepted October 8, 2020

Mss. Clausen, Bakken, Mr. Westbye, and Prof. Skokauskas are with The Norwegian University of Science and Technology (NTNU), Faculty of Medicine & Health Sciences; Regional Center for Child and Youth Mental Health and Child Welfare-RKBU, Central Norway, Trondheim, Norway. Mr. Westbye is also with St. Olavs Hospital, Trondheim, Norway. Dr. Leventhal is with The University of California San Francisco (UCSF), San Francisco. Dr. Nytrø, Mr. Røst and Ms. Koochakpour are with The Norwegian University of Science and Technology (NTNU), Faculty of Information Technology and Electrical Engineering, Trondheim, Norway. Prof. Koposov is with UiT- The Arctic University of Norway, Regional Center for Child and Youth Mental Health and Child Welfare-RKBU, Northern Norway, Tromsø, Norway; and Sechenov First Moscow State Medical University, Moscow, Russia. Mr. Thorvik is with Central Norway Regional Health Information Technology (HEMIT).

Funding was received from the Norwegian Research Council (269117).

Author Contributions
Conceptualization: Clausen, Leventhal, Skokauskas
Supervision: Leventhal, Nytrø, Skokauskas
Visualization: Nytrø, Skokauskas
Writing – original draft: Clausen, Skokauskas
Writing – review and editing: Clausen, Leventhal, Nytrø, Koposov, Westbye, Røst, Bakken, Koochakpour, Thorvik, Skokauskas

ORCID
Carolyn E. Clausen, MSc: https://orcid.org/0000-0003-2121-7252
Bennett L. Leventhal, MD: https://orcid.org/0000-0001-6985-3691
Øystein Nytrø, PhD: https://orcid.org/0000-0002-8163-2362
Roman Koposov, MD, PhD: https://orcid.org/0000-0002-7393-2920
Odd Sverre Westbye, MSc:
Thomas Brox Røst, MSc: https://orcid.org/0000-0001-8395-7868
Victoria Bakken, MSc:
Kaban Koochakpour, MSc: https://orcid.org/0000-0001-7214-8651
Ketil Thorvik, BA: https://orcid.org/0000-0002-5990-4405
Norbert Skokauskas, MD, PhD:

Disclosure: Dr. Leventhal has received support from Janssen/JandJ and has served on the CMI Scientific Advisory Board. Dr. Nytrø, Profs. Koposov and Skokauskas, Ms. Clausen, Messrs.

Westbye and Røst, Mss. Bakken and Koochakpour, and Mr. Thorvik have reported no biomedical financial interests or potential conflicts of interest.

Several trade names are mentioned in the paper. Deontics is decision software used in the IDDEAS project. OncoDoc2, CHICA and Google Convolutional Neural Networks are cited simply to provide examples for the reader to explore if they are interested. The name IDDEAS belongs to the Norwegian Consortium developing a children and adolescent mental health clinical decision support system. It is not a commercial product.

Correspondence to Prof. Norbert Skokauskas, PhD, MD, Regional Centre for Child and Youth Mental Health and Child Welfare, Central Norway, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology , Klostergata 46, 7030 Trondheim, Norway; e-mail: norbert.skokauskas@ntnu.no

"Healing is a matter of time, but it is sometimes also a matter of opportunity."

-Hippocrates[1]

In the "good old days," Hippocrates narrowed the basic understanding of disease and clinical practice to four "humors": blood, phlegm, yellow bile and black bile. Today, medical practice takes place in a rapidly expanding realm of an ever-changing knowledge base that makes it difficult to include all evidence-based information about etiology, epidemiology, phenomenology, assessment, prevention, treatment, and more, in day-to-day patient care. This is made more challenging by the complexity and growing interest in "personalized medicine" and "precision medicine." While some clinicians read widely and have prodigious memories, few of us are able to apply all available, pertinent knowledge to our patients' care. We do have options. We can revert to the four humors. Better yet, we can look for modern technology to support complex clinical practice with computer capacity and artificial intelligence. These innovative processes have been captured for clinical use in what is referred to as Clinical Decision Support Systems (CDSSs).

What is a Clinical Decision Support System?

Patient electronic health records (EHRs) are readily available to practitioners but rarely provide adequate insight into complex clinical situations intrinsic to psychiatric care, including how best to address newly-developed biological frameworks for disorders, emerging methods for phenotyping symptoms, and identifying syndromes.[2] A CDSS can offer evidence-based guidance by using practice parameters, standardized guidelines, evolving scientific literature, and/or datasets compiled from actual experience, assembled in a scalable informatics framework. Essentially, a CDSS accesses large amounts of information and then uses algorithms for matching patient conditions and phenotypic patterns to the most relevant recommendations, so as to provide the most pertinent information and alternative actions, at each step in the clinical decision-making process. A CDSS is not a replacement for practitioners. It is designed to offer practitioners optimal, individualized, real-time support. A CDSS allows practitioners to apply compiled evidence so that each patient receives efficient, effective, and customized care at every encounter.[3,4]

Functionality of a Clinical Decision Support System

CDSS architecture typically includes three parts:

1. *Knowledge Base* – the domain of expertise, translated into rules, decision trees, or process models;
2. *Reasoning Engine* – applies the domain of knowledge to clinical findings and the patient EHR and, then, ranks the advisable clinical actions;
3. *User Interface* – electronic display that provides alerts, accepts queries, and provides relevant, timely recommendations for the clinician (see Figure 1).[3,4]

Generally, the Knowledge Base is designed to store evidence from clinical guidelines, patient health datasets, and the scientific literature. While guidelines can be aggregated and modeled to provide suggested care pathways, the use of "big data" in a CDSS requires analytics/data mining to identify relevant patterns within extensive data/databases.[5] Data from various patient data sources are mapped into a hierarchically-structured domain of inter-related concepts. The mapping is done using artificial intelligence (AI)-based and AI-trained classifiers that identify patterns in patient data.[3,4] The hierarchical care patterns are first shared with the Knowledge Base before being sent to the Reasoning Engine to be ranked and, then, delivered to the User Interface to assist the clinician.[5]

The care patterns generated by the CDSS are not intended to be prescriptive. Rather, they serve as an experience-based process map to provide advice and guidance. Prior to implementation of the CDSS, actively practicing clinicians will pilot test the system to ensure it is reliable, valid, and relevant for clinical practice. When the CDSS is integrated with the patient's EHR, the Reasoning Engine sends alerts or prompts to the clinician. These prompts, customized to meet clinical needs during the patient encounter (i.e., medication reminders, etc.), are displayed in the User Interface within the patient's EHR. The process is activated when the EHR is opened. De-identified patient information is shared with the Reasoning Engine, avoiding the need for the clinician to manually input each patient's information. Afterwards, the analysis of the data and relevant information are returned to the clinician. In this way, each patient receives individualized care based on big data analytics while the patient's de-identified clinical information contributes to the expansion of the database for decision-making support. With this type of artificial intelligence, the system's database continuously learns and expands in light of treatment occurrences.[3,5] If the CDSS reasoning engine is not integrated with the EHR, the User Interface is either a web or computer/smart device-based application.[4]

A CDSS is a dynamic tool that supports clinical care in real-time. Optimally, it is curated, so that the generated recommendations for clinicians are “up-to-date” with the ever-growing body of scientific evidence and guidelines. This functionality assures the CDSS is sustainable and adaptable for evolving clinical needs and care standards.[3,5]

Development of Clinical Decision Support Systems

Multiple medical specialties have produced evidence about CDSS effectiveness, including medical oncology (i.e., OncoDoc2),[6] endocrinology (i.e., CHICA),[7] and ophthalmology (i.e., Google Convolutional Neural Networks).[8] Incorporating data-driven decision-making in child and adolescent mental health services (CAMHS) is still relatively novel.[2] One such approach is the **I**ndividualized **D**igital **DE**cision **A**ssist **S**ystem (IDDEAS), a broad-spectrum, guideline- and data-based CDSS being built to improve diagnosis and treatment of child and adolescent mental health disorders in Norway. IDDEAS uses aggregated clinical guidelines, practice parameters, and clinical care datasets from multiple sources (e.g., patient and user registries, youth public health surveys, etc.). This CDSS will be integrated with the patient EHR (see Figure 1).

The development of a knowledge-based CDSS, augmented by big data, often occurs as follows: 1) collecting and validating clinical evidence; 2) modeling for clinical practice; and, 3) aggregating and evaluating big data. Evidence collection entails compiling relevant practice parameters, clinical guidelines, and scientific literature, to be held in the Knowledge Base.[3] Recommendations are shared with practitioners for validation, prior to modeling and encoding.[9] With IDDEAS, community-based child and adolescent psychiatrists, and other stakeholders, joined the project consortium, enabling a collaborative, targeted approach to validating the Knowledge Base clinical content that supports clinicians.[9]

Upon validation, all practice parameters and guidelines are encoded as clinical pathway models, using web ontology language (OWL) and AI-based classifiers. They are then stored using decision support software (e.g., Deontics, Screenworks, London, UK) linked to the Knowledge Base.[10] The guidelines are commonly represented as a “decision tree” in order to provide step-by-step support through diagnostic and treatment decision-making.[3,4] AI-based classifiers are selected based on the structure of the included data and the objectives of the system. A hybrid CDSS, like IDDEAS, uses a mix of AI-based classifiers, including machine-learning algorithms (i.e., clustering) for big data analytics, in order to provide guidance based on practice parameters and similar patient cases.[3]

The final step involves aggregating any and all available healthcare datasets (i.e., demographic data, patient clinical data, laboratory data, imaging data, etc.) within the Knowledge Base.[5] IDDEAS, for example, utilizes rich datasets derived from multidisciplinary EHRs, accrued over the past decade by the Norwegian National Association of Child and Adolescent Mental Health. Because psychiatric health data are often inaccessible, access to aggregated health datasets requires compliance with ethical clearance and data protection parameters. Once approved, all records are de-identified before sharing with the Knowledge Base and Reasoning Engine.

Reliability and utility of the CDSS in practice are often evaluated using fictional patient case examples and clinical focus groups; this ensures that the Knowledge Base provides sufficient evidence for the Reasoning Engine to rank and offer relevant recommendations.[9] Clinicians must be able to quickly view and interpret CDSS recommendations while feeling assured that their queries receive appropriate, timely responses. This makes the design and implementation of the User Interface critical. The fictional patient case examples can be used to test how well the system addresses clinicians' queries, based on both the patient's needs and the evidence in the Knowledge Base.[9]

For IDDEAS, a patient-oriented design is important in system development as Norwegian patients have access to their EHRs, making it possible for them to discuss their evaluations, specific diagnoses and treatments with their clinician. This level of participation allows the patient, and their family, to be more involved in their own care, while also improving understanding of clinical management and how decisions are made.[3,4]

Strengths and Weaknesses of Clinical Decision Support Systems

CDSSs improve patient safety and quality of care for multiple medical conditions by integrating individual patient data and evidence databases to facilitate clinical decision-making.[4] CDSSs can potentially use existing resources to provide similar decision support for

CAMHS while providing earlier access to care and reducing inefficiency, including the costs of unnecessary testing, misdiagnosis, and suboptimal clinical management.[2]

While CDSSs have a generally favorable profile, risks also exist. The most common challenges relate to data-availability and confidentiality, with the reuse of clinical information within the system.[4] Analysis of individuals' health data raises concerns about de-identification of personal health information, requiring ethical clearance and data access approval; IDDEAS also adheres to General Data Protection Regulations (GDPR).[4] Another significant challenge for CDSS implementation is creating a system that is value-added for the practitioner, user-friendly, and improves care.[2-4] AI allows the CDSS to consider assimilation and cultural bias that arises, based on the evident frequency of a treatment, rather than just clinical validity.[3,5] Even the best CDSS may fail if its utility and usability do not directly benefit clinicians. Therefore, practicing clinicians must be included in development, testing, implementation, and evaluation of each CDSS. For IDDEAS, the clinicians are invited to share perspectives on the CDSS with child and adolescent mental health colleagues in Norway and beyond, as part of an international dissemination plan for future CDSS projects.[9]

Conclusion

Hippocrates suggested that we seize the opportunity to improve the care for our patients. In addition to continuing to use guidelines and electronic health records, other technological innovations can improve the effectiveness and efficiency of child and adolescent psychiatry practice. CDSSs are opportunistic, technological innovations that aggregate evidence-based care and valuable clinical wisdom in order to diagnose, prevent, and treat psychiatric disorders in children and adolescents. To seize this opportunity, child and adolescent psychiatrists, and other mental health professionals, must take a leading role in guiding prompt development and implementation of CDSSs, to improve our efficiency and effectiveness, as well as to expand our reach. We are faced with a choice: *Carpe Diem?* or *Carpe Cras (mañana)?*

References

1. Hippocrates c.460-357 BC Greek physician. *Precepts* ch. 1 (tr. W. H. S. Jones), Oxford Essential Quotations (4 ed.), Susan Ratcliffe, ed. Publisher: Oxford University Press, Published online 2016, eISBN: 9780191826719.

2. Koposov R, Fossum S, Frodl T, et al. Clinical decision support systems in child and adolescent psychiatry: a systematic review. Eur Child Adolesc Psyciatry. 2017; 26:1309-1317.

3. Berner ES (ed.), La Lande TJ. Clinical Decision Support Systems: Theory and Practice, Health Informatics. Third Edition. Springer International Publishing. Switzerland. 2016: 1-17.

4. Sutton RT, Pincock D, Baurngart DC, et al. An overview of clinical decision support systems: benefits, risks, and strategies for success. npj Digital Medicine. 2020;3: 17. https://doi.org/10.1038/s41746-020-0221-y.

5. Dagliati A, Tibollo V, Sacchi L, et al. Big data as a driver for clinical decision support systems: A learning health systems perspective. Frontiers in Digital Humanities. 2018;5(8): 1-7.

6. Séroussi B, Bouaud J, Antoine É. OncoDoc, a successful experiment of computer-supported guideline development and implementation in the treatment of breast cancer. Artif Intell Med. 2001;22(1): 43-64.

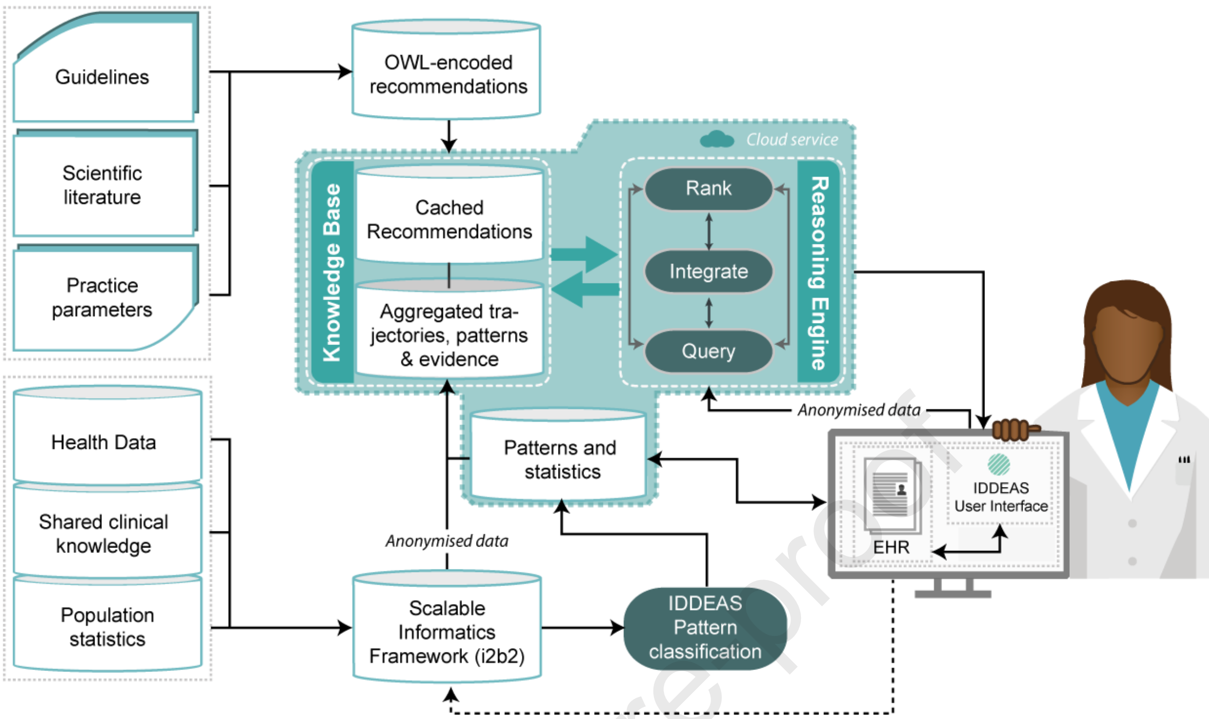
7. Hannon TS, Dugan TM, Saha CK, et al. Effectiveness of computer automation for the diagnosis and management of childhood type 2 diabetes: A randomized clinical trial. JAMA Pediatr. 2017;171(4): 327-334.

8. Gulshan V, Peng L, Coram M, et al. Developmental and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. JAMA- J. Am. Med. Assoc. 2016;316, 2402-2410.

9. Weltermann B, Kersting C. Feasibility study of a clinical decision support system for the management of multimorbid seniors in primary care: study protocol, BMC Pilot and Feasibility Studies. 2016;2(16):1-9. doi: 10.1186/s40814-016-0057-z.

10. Deontics. Deontics Clinical Features. London, United Kingdom: Deontics, Screenworks; 2020 [updated 2020; cited 2019 Oct]. Available from: https://deontics.com/

Figure 1. Individualized Digital DEcision Assist System (IDDEAS)
Note: *EHR= Electronic Health Record; OWL=Web Ontology Language;
IDDEAS=Individualized Digital DEcision Assist System



Guidelines
Scientific literature
Practice parameters
OWL-encoded recommendations
Cloud service
Knowledge Base
Cached Recommendations
Aggregated trajectories, patterns & evidence
Rank
Integrate
Query
Reasoning Engine
Health Data
Shared clinical knowledge
Population statistics
Patterns and statistics
Anonymised data
Anonymised data
IDDEAS User Interface
EHR
Scalable Informatics Framework (i2b2)
IDDEAS Pattern classification