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Digitizing U.S. Air Force Medical Standards for the Creation and Validation of a Readiness Decision Support System

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ABSTRACT

Introduction

Deployment-limiting medical conditions are the primary reason why service members are not medically ready. Service-specific standards guide clinicians in what conditions are restrictive for duty, fitness, and/or deployment requirements. The Air Force (AF) codifies most standards in the Medical Standards Directory (MSD). Providers manually search this document, among others, to determine if any standards are violated, a tedious and error-prone process. Digitized, standards-based decision-support tools for providers would ease this workflow. This study digitized and mapped all AF occupations to MSD occupational classes and all MSD standards to diagnosis codes and created and validated a readiness decision support system (RDSS) around this mapping.

Materials and Methods

A medical coder mapped all standards within the May 2018 v2 MSD to 2018 International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) codes. For the publication of new MSDs, we devised an automated update process using Amazon Web Service's Comprehend Medical and the Unified Medical Language System's Metathesaurus. We mapped Air Force Specialty Codes to occupational classes using the MSD and AF classification directories. We uploaded this mapping to a cloud-based MySQL (v5.7.23) database and built a web application to interface with it using R (v3.5+). For validation, we compared the RDSS to the record review of two subject-matter experts (SMEs) for 200 outpatient encounters in calendar year 2018. We performed four separate analyses: (1) SME vs. RDSS for any restriction; (2) SME interrater reliability for any restriction; (3) SME vs. RDSS for specific restriction(s); and (4) SME interrater reliability for categorical restriction(s). This study was approved as "Not Human Subjects Research" by the Air Force Research Laboratory (FWR20190100N) and Boston Children's Hospital (IRB-P00031397) review boards.

Results

Of the 709 current medical standards in the September 2019 MSD, 631 (89.0%) were mapped to ICD-10-CM codes. These 631 standards mapped to 42,810 unique ICD codes (59.5% of all active 2019 codes) and covered 72.3% (7,823/10,821) of the diagnoses listed on AF profiles and 92.8% of profile days (90.7/97.8 million) between February 1, 2007 and January 31, 2017. The RDSS identified diagnoses warranting any restrictions with 90.8% and 90.0% sensitivity compared to SME A and B. For specific restrictions, the sensitivity was 85.0% and 44.8%. The specificity was poor for any restrictions (20.5%–43.4%) and near perfect for specific restrictions (99.5+%). The interrater reliability between SMEs for all comparisons ranged from minimal to moderate ($\kappa = 0.33$–0.61).

Conclusion

This study demonstrated key pilot steps to digitizing and mapping AF readiness standards to existing terminologies. The RDSS showed one potential application. The sensitivity between the SMEs and RDSS demonstrated its viability as a screening tool with further refinement and study. However, its performance was not evenly distributed by special duty status or for the indication of specific restrictions. With machine consumable medical standards integrated within existing digital infrastructure and clinical workflows, RDSSs would remove a significant administrative burden from providers and likely improve the accuracy of readiness metrics.

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INTRODUCTION

Background

The primary mission of the Military Health System (MHS) is readiness [1]. This entails ensuring our uniformed members are medically fit for their assigned duties, particularly while deployed. Deployment-limiting medical conditions [2] are the primary reason why service members are not medically ready [3–5]. Each branch publishes service-specific standards designed to guide clinicians in deciding what medical conditions are disabling (and waiverable) for certain occupations, fitness exam components, and deployments.

The Air Force (AF) codifies its retention, duty, and deployment standards in the Medical Standards Directory (MSD) [6]. With each encounter, providers crosscheck the AF member's medical condition and occupation with the appropriate MSD and fitness standards. Currently, the MSD only exists in portable document format (PDF), meaning providers must manually search this 70-page PDF. For members in violation, and particularly for special duty occupations, providers should reference Air Force Instructions (AFIs) 48-123 (7) and 10-203 (8), the AF Waiver Guide [9], and multiple medication lists [10–12]. These documents again exist exclusively as PDFs, range from 4 to 900+ pages in length, and are stored across multiple information systems. Updates to these documents are not scheduled, and providers do not receive any notifications when new versions become available.

Nonflight surgeon providers also never receive any occupational medicine training with commissioning, and associating medical conditions with occupational restrictions is not part of traditional clinical residencies or fellowships. With minimal training and an administratively cumbersome process, providers unsurprisingly fail to make occupational dispositions within the standard of care 53% of the time [13]. However, the importance of accurate occupational dispositions to the readiness mission and codification of existing standards together argue for the importance and feasibility of creating readiness decision support systems (RDSSs) for medical providers.

Potential Readiness Decision Support

Outside retention standards, MSD standards vary by Air Force Specialty Code (AFSC), the terminology scheme for AF occupations. Duty AFSCs divide into special and nonspecial duty. The September 2019 MSD splits special duty standards into eight groups [6]. Most special duty AFSCs divide cleanly into at least one of these groupings. The MSD and AF classification directories [14,15] provide guidance on how to categorize AFSCs. For nonspecial duty occupations, the vast majority of Airmen, only retention and deployment standards apply. However, fitness standards apply across all occupations [16].

MSD standards also encompass a description that helps providers decide the applicability of each respective standard. These descriptions contain diagnostic information that could be used to link the MSD to existing medical terminologies, such as the Systematized Nomenclature of Medicine–Clinical Terms or International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM). Digitizing and mapping MSD standards and AFSCs to medical terminologies would improve our ability to track population readiness and enable the creation of RDSSs for frontline clinicians.

Objectives

This study has two objectives. First, we aim to digitize and map all AFSCs to MSD occupational classes and all MSD standards to ICD-10-CM codes. Second, we plan to create and validate a highly sensitive RDSS around this mapping that demonstrates one impactful application of digitizing medical standards and linking them to existing terminologies.

METHODS

Medical Standards to ICD-10-CM Code Mapping

A trained medical coder manually mapped all 705 medical standards within the May 2018 v2 MSD (17) to 2018 ICD-10-CM codes [18]. Each standard could map to zero, one, or many ICD-10-CM codes. Four medical and military professionals, including two authors (C.C.U. and M.G.B.), manually validated this mapping. Over the course of the study period, the AF released five new editions of the MSD [6,19–22], and the Centers for Medicare and Medicaid published 2019 ICD-10-CM codes [23].

With the frequent publication of new MSDs, we devised an automated process to update the mapping, leveraging two application programming interfaces (APIs). First, using Python v3.3+ and boto v2.49.0, we passed the text description of each updated standard to Amazon Web Service's (AWS's) medical text natural language processing service, Comprehend Medical [24]. These API calls returned each "medical entity" within the description of the standards. Only those recognized as "medical conditions" were kept.

Using R v3.5+ and RStudio, we passed these medical entities to the Unified Medical Language System's (UMLS's) Metathesaurus using their API [25]. These API calls returned all ICD-10-CM codes for each entity. Search type was set as "words". After manual verification, we addended the previous mapping file, removing duplicate ICD-standard pairs.

AFSC to Occupational Class Mapping

The Air Force Enlisted Classification Directory (AFECD) and Air Force Officer Classification Directory (AFOCD) list the qualifications of each AFSC. One author (C.C.U.) used the April 2018 edition of these documents [26,27] to manually map individual AFSCs to one of the eight occupational classes listed in the May 2018 v2 MSD [17]. With each

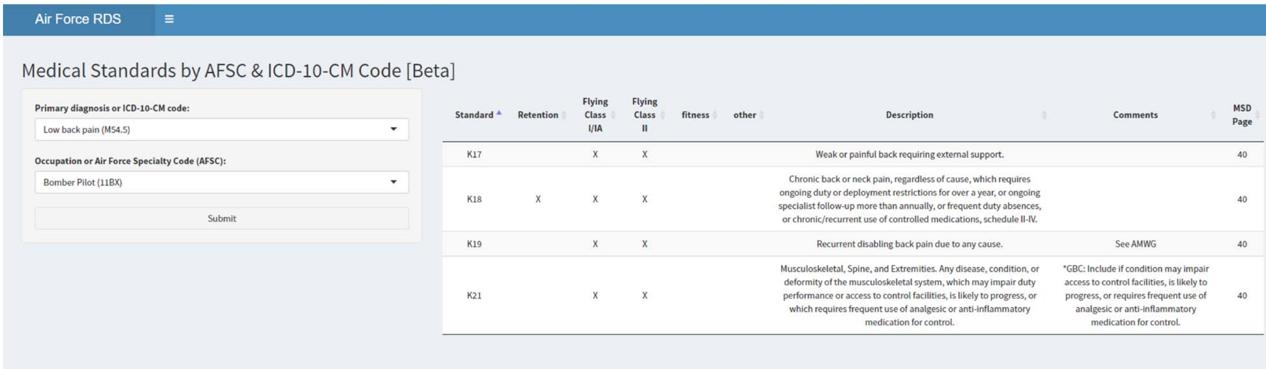

FIGURE 1. Screenshot of RDS tool (https://www.airforcerds.com). AFSC, Air Force specialty code; AMWG, aeromedical waiver guide; RDS, readiness decision support; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification; MSD, medical standards directory.

version between October 2018 and October 2019 [14,15,26,27], the same author (C.C.U.) updated the AFSC-to-occupational-class mapping. The May 2019 MSD (21) added a ninth occupational class that necessitated an additional update.

Relational Database and World Wide Web Application Design

Using a MySQL Microsoft Excel plugin, we converted the mapping spreadsheets into four MySQL (v5.7.23) tables and uploaded them to the Amazon Relational Database Service.

Built with R (v3.5+), RStudio, and Shiny, the RDSS web application interfaces with the relational database. Users enter the ICD-10-CM diagnosis and the AFSC of the service members, and the application, available at https://www.airforcerds.com, returns the applicable medical standard(s) (Fig. 1).

RDSS Validation

To validate the RDSS, we designed a cross-sectional study to compare it to two independent subject-matter experts (SMEs). One SME is the current chief of aerospace medicine at an AF base, and the other is a current resident in aerospace medicine and multiyear consultant with the Aeromedical Consult Service.

Our validation sample included 200 outpatient encounters on active duty AF members in calendar year 2018 documented in the Armed Forces Health Longitudinal Technology Application (AHLTA): Department of Defense Identification Number (DoD ID), encounter date, ICD-10-CM codes, and AFSCs. Half the encounters were for Airmen with duty AFSCs indicating a special duty status. Exclusion criteria included Airmen pregnant, undergoing a medical evaluation board, with permanent deployment restrictions, ranked above O-6 (colonel), or without an AFSC. SMEs used this information to find each encounter in AHLTA and record the medical standards that each diagnosis from each encounter violated, if any. They also indicated if diagnoses warranted duty, fitness, and/or deployment restrictions. Both SMEs were blinded to the output from the RDSS and the other SME. Based on the RDSS output and SME review, we performed four analyses (Fig. 2). Calculated measures included sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV) for SME vs. RDSS comparisons and Cohen's kappa statistic for interrater reliability (agreement) between SMEs.

This study was approved as "Not Human Subjects Research" by the Air Force Research Laboratory (FWR2019-0100N) and Boston Children's Hospital (IRB-P00031397) review boards.

RESULTS

Medical Standards and Job Class Mapping

Of the 709 current medical standards in the September 2019 MSD [6], 631 (89.0%) were specific enough to be mapped to one or more ICD-10-CM codes. We deemed the remaining standards "too vague". These 631 standards mapped to 86,104 total ICD-10-CM codes, 42,810 that were unique, representing 59.5% of those active in 2019. Thus, on average each standard mapped to 136.5 ICD codes. These mapped standards covered 72.3% (7,823/10,821) of the unique diagnoses listed on AF profiles and 92.8% of profile days (90.7/97.8 million) between February 1, 2007 and January 31, 2017 [28].

Record Review Study Sample

Of the 200 outpatient encounters identified through this study's data request, only 186 were retrievable within AHLTA for review by the SMEs. These 186 encounters contained 249 ICD-10-CM diagnoses. Of these encounters, 66 were for special duty personnel with the remaining 120 being nonspecial duty. For diagnoses, 84 were for special duty, 165 nonspecial duty. Although the study design intended for a 1:1 special duty:nonspecial duty stratification, a coding error in one AFSC (1W0X1 Weather) led to the imbalance.

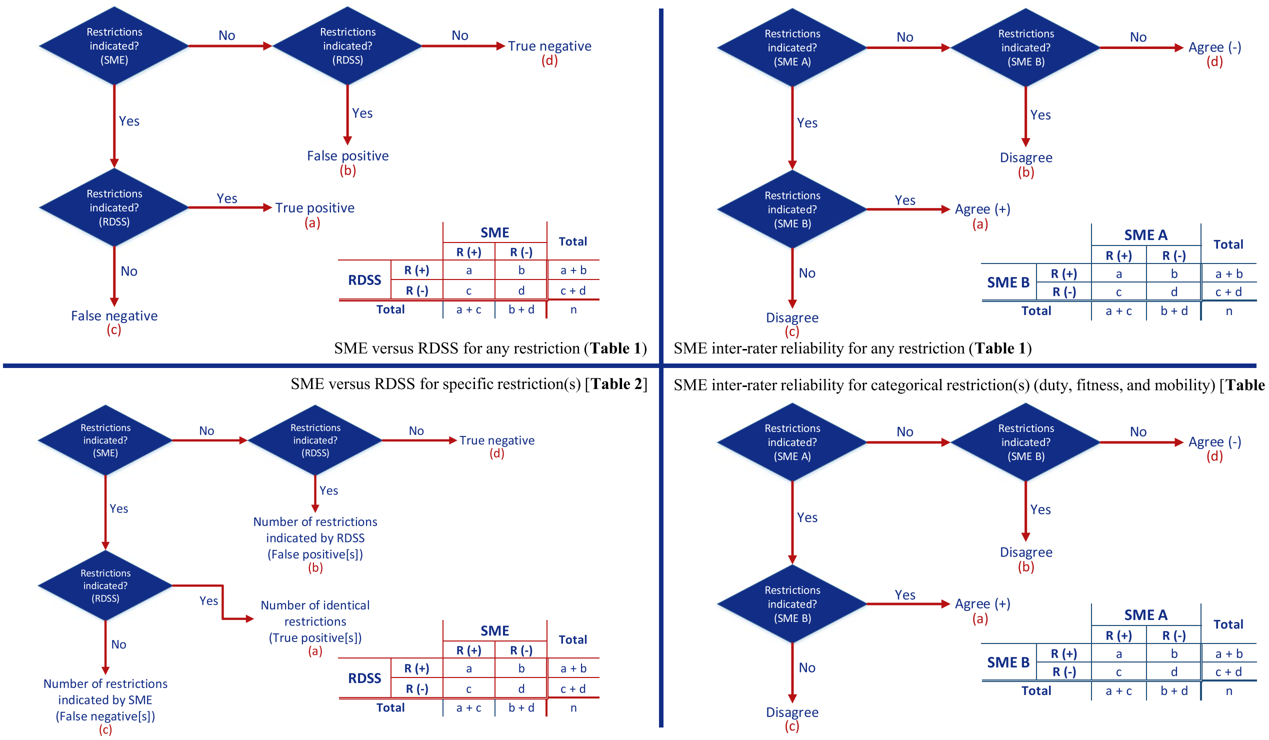

FIGURE 2. Flow diagrams for calculating the summary statistics and interrater reliability for the indication of any (binary yes/no), specific (per the September 2019 Medical Standards Directory), and categorical occupational restrictions between SMEs and the RDSS. RDSS, readiness decision support system; R, restrictions; SME, subject-matter expert.

Presence/Absence of Any Occupational Restriction

Overall, the RDSS identified diagnoses warranting restrictions with 90.8% and 90.0% sensitivity compared to SME A and B. The NPV was similarly high at 90.2% and 82.3%, although the specificity and PPV were markedly lower, ranging from 30.4% to 53.2% across both SMEs (Table 1).

Stratifying by special duty status produced a similar trend in results, high sensitivity and NPV and low PPV and specificity, except for NPV in SME B, which was 47.1%. Additionally, the RDSS performed markedly better in nonspecial duty personnel with a sensitivity of 92.9% and 97.0% vs. 87.0% and 79.5% in special duty across SME A and B. The NPV and specificity remained low in both groups, ranging from 20.5% to 53.3%, albeit somewhat higher in nonspecial duty.

The agreement between SMEs for the presence of any occupational restriction was weak (κ = 0.42) with some discrepancy between special and nonspecial duty personnel, 0.33 and 0.47.

Indication of Specific Occupational Restrictions

Table II compares the RDSS to each SME regarding the indication of specific occupational restrictions and each SME to each other regarding the presence of categorical duty, fitness, and/or deployment restrictions. Overall, the specificity, PPV, and NPV of the RDSS were similar across the two SMEs. The specificity and NPV were nearly perfect, ranging from 99.5% to 100.0%, although the PPV was 19.3% and 32.5%. These results were similar when stratified by special duty status. The sensitivity of the RDSS though was considerably different—85.0% in SME A and 44.8% in SME B. Sensitivity also varied by special duty status—100.0% and 82.4% in SME A for special and nonspecial duty and 55.3% and 39.8% in SME B.

The agreement between SMEs for categorical occupational restrictions (duty, fitness, and/or deployment) was overall weak for duty and fitness restrictions (κ = 0.44 and 0.45, respectively) but moderate for deployment restrictions (κ = 0.61). Stratifying by special duty status did not significantly affect the agreement for deployment restrictions, although we noted some difference between duty and fitness restrictions. Albeit still weak or minimal, for fitness restrictions, SMEs had higher agreement for nonspecial duty personnel (0.48 vs. 0.38), and we found the opposite trend for duty restrictions (0.53 vs. 0.33).

DISCUSSION

This study demonstrated key pilot steps to digitizing AF medical readiness standards and mapping them to existing terminologies. Most medical standards (89.0%) mapped to ICD-10-CM codes, and the classification of AFSCs was straightforward, minus those belonging to Operational Support Flying Duty. We easily deployed this mapping to a cloud-based

TABLE I. Summary Statistics and Interrater Reliability Comparing the Indication of Any Occupational Restriction (Binary Yes/No) Between SMEs and the RDSS, by Special Duty Status

	Sensitivity	Specificity	PPV	NPV	κ
Total (n_e = 186; n_d = 249)					
SME A vs. RDSS	90.8%	30.4%	31.9%	90.2%	-
SME B vs. RDSS	90.0%	37.0%	53.2%	82.3%	-
SME A vs. SME B	-	-	-	-	0.42
Special duty (n_e = 66; n_d = 84)					
SME A vs. RDSS	87.0%	21.7%	29.9%	81.3%	-
SME B vs. RDSS	79.5%	20.5%	53.0%	47.1%	-
SME A vs. SME B	-	-	-	-	0.33
Nonspecial duty (n_e = 120; n_d = 165)					
SME A vs. RDSS	92.9%	34.7%	33.1%	93.3%	-
SME B vs. RDSS	97.0%	43.4%	53.3%	95.6%	-
SME A vs. SME B	-	-	-	-	0.47

Note: Data based on a record review of randomized outpatient medical encounters documented in AHLTA during the study period (January 1, 2018–December 31, 2018). κ, Cohen's kappa statistic; RDSS, readiness decision support system; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification; n_d, number of encounters; n_e, number of ICD-10-CM diagnoses; NPV, negative predictive value; PPV, positive predictive value; SME, subject-matter expert.

relational database, accessible by any developer with appropriate permissions. The RDSS utilizing this service showed one potential application. The overall high sensitivity and NPV between the SMEs and RDSS (Table I) for the indication of any restriction demonstrated its potential viability as a screening tool.

Several results of the mapping and validation process warrant deeper discussion. We could not map 11.0% of the standards to ICD-10-CM codes because their description was too vague. This mapping failure reveals both an initial design decision of the RDSS and a current weakness in connecting standards to medical terminologies. To increase our overall mapping percentage, we could have mapped these standards to thousands of ICD-10-CM codes. Since our main focus with the RDSS was sensitivity and cueing the provider to potential applicable standards, this strategy might be a worthwhile consideration with the next iteration. A few standards within each MSD section (head and neck, skin, etc.) need to be "catch alls" for conditions that may limit the duty or deployability of uniformed members but not fit the specific criteria of other standards. This nature of medical standards prohibits mapping to a narrow set of codes from any terminology. However, the descriptions of several, unmapped standards reference medications and specialty referrals. Additional sources integrating these data points could refine the mapping and therefore the performance of the RDSS.

Although the RDSS's sensitivity for the overall indication of restrictions (Table I) was encouraging, its performance was not evenly distributed by special duty status or for the indication of specific restrictions (Table II). The sensitivity for the indication of any restriction was lower for special duty AFSCs, particularly for SME B (Table I). Although the misapplication of standards in special duty populations is more consequential, the process involves more complicated decision making and likely varies by familiarity and past experiences with specific populations. Thus, the poorer performance of the RDSS for special duty AFSCs is not surprising.

The sensitivity of the RDSS for specific restrictions (Table II) also varied heavily by SME, with sensitivity in comparison to SME A almost doubling that in SME B both overall and by special duty status. This discrepancy between SMEs likely involved several factors and is probably less meaningful than it appears. The case of low back pain (M54.5) in a financial management and comptroller (AFSC: 6F0X1) helps illustrate. For this encounter, the RDSS output the standard K18; SME B said K17; SME A, K18. Both K17 and K18 involve back pain albeit with different descriptions and intentions of applicability. Operationally though, the difference is likely trivial. If the individual received an occupational disposition with appropriate restrictions and return-to-work recommendations, the exact standard violated is not consequential. However, this nuanced judgment between similar standards does not completely explain the sensitivity discrepancy between SMEs in Table II. The small sample size, variable record review instructions interpretations, different clinical backgrounds and experiences, and lack of enterprise attention on their consistent application may all take some responsibility for the difference.

These reasons also help explain the poor to weak agreement between SMEs for both the indication of any (Table I) and specific (Table II) restrictions. SMEs also noted that most of the study samples were follow-up encounters, particularly physical therapy appointments. These encounters were sparse for details and led the SMEs to surmise the full history of the diagnosis and its respective limitations. Limiting the sample to initial encounters with full diagnosis histories might have improved both RDSS performance and SME agreement. However, given the readiness importance of correct occupational

TABLE II. Summary Statistics and Interrater Reliability Comparing the Indication of Specific Occupational Restrictions (per the September 2019 Medical Standards Directory) Between SMEs and the RDSS, by Special Duty Status

	Sensitivity	Specificity	PPV	NPV	κ_{Duty}	$\kappa_{Fitness}$	$\kappa_{Deployability}$
Total (n_e = 186; n_d = 249)							
SME A vs. RDSS	85.0%	99.5%	19.3%	100.0%	-	-	-
SME B vs. RDSS	44.8%	99.8%	32.5%	99.9%	-	-	-
SME A vs. SME B	-	-	-	-	0.44	0.45	0.61
Special duty (n_e = 66; n_d = 84)							
SME A vs. RDSS	100.0%	99.5%	20.0%	100.0%	-	-	-
SME B vs. RDSS	55.3%	99.7%	26.3%	99.9%	-	-	-
SME A vs. SME B	-	-	-	-	0.53	0.38	0.58
Nonspecial duty (n_e = 120; n_d = 165)							
SME A vs. RDSS	82.4%	99.6%	19.2%	100.0%	-	-	-
SME B vs. RDSS	39.8%	99.8%	38.6%	99.9%	-	-	-
SME A vs. SME B	-	-	-	-	0.33	0.48	0.61

Note: Data based on a record review of randomized outpatient medical encounters documented in AHLTA during the study period (January 1, 2018–December 31, 2018). κ, Cohen's kappa statistic; RDSS, readiness decision support system; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification; n_d, number of encounters; n_e, number of ICD-10-CM diagnoses; NPV, negative predictive value; PPV, positive predictive value; SME, subject-matter expert.

dispositions and the concordance of this result with prior findings comparing SMEs to primary care physicians [13], more research is warranted.

Despite the importance of this work to the readiness mission, a paucity of research exists for any additional direct comparisons. To our knowledge, this is the first study to develop and use a decision-support tool to help military medical providers apply occupational standards. The uniqueness of military medicine in this context also limits civilian corollaries. Nonmilitary occupational medicine professionals apply standards around work-related physicals, but clinical decision-support systems (CDSSs) around the correct selection of standards do not exist. Several proprietary decision aids—the Official Disability Guide (MCG Health, Seattle, Washington, USA) and MDGuidelines (Reed Group, Westminster, Colorado, USA)—exist, but both help providers determine appropriate restrictions and length of disability, not the occupation-specific standard violated [29].

CDSSs though have widespread evidence regarding their potential utility and how to deploy them effectively [30–37]. The RDSS is a CDSS that reminds providers of the applicable medical standards given the diagnosis and occupation of a patient. This concept is similar to CDSS reminders shown to improve the delivery of preventive health services and other process metrics [38–45]. Ideally, we would implement it within the future military electronic health record, MHS Genesis, as a backend service using existing interoperability technologies such as Substitutable Medical Applications, Reusable Technologies (SMART) [46] on Fast Healthcare Interoperability Resources (FHIR) [47] and CDS Hooks [48]. Information or suggestion cards [48] with the recommended medical standards would appear after the provider codes the diagnosis(es) within the assessment and plan of a clinical note in MHS Genesis. The system could also integrate provider selections and modify the recommended standards through reinforcement machine learning.

LIMITATIONS

Although we discussed the strengths of the RDSS with its sensitivity and NPV, the PPV and specificity were poor for the indication of any restriction (Table I) and falsely elevated for specific restrictions (Table II). For any restrictions, we expected poor specificity and PPV given the screening nature of the RDSS and the vague nature of many medical standards. We designed the RDSS to give medical providers a list of potential standards from which to choose without having to reference the entire MSD. The high specificity and NPV for specific standards merely reflect that the RDSS only returned a narrow set of standards; all the standards that it did not return and were not indicated by the respective SME were true negatives (Fig. 2).

The small sample size and the poor agreement between the SMEs also bring question to the merits of the validation. Comparing the RDSS to additional SMEs with a larger sample of encounters, particularly for special duty AFSCs, would be required before piloting in any production environment. The RDSS also exists outside the workflow of military practitioners. This is far from ideal and only meant to demonstrate its functionality that should be integrated within the electronic health record rather than a separate siloed system.

The initial manual mapping of MSD standards to ICD-10-CM codes was also labor intensive and prone to human error, despite multiple validations. The MSD, AFE/OCDs, and ICD-10-CM codes updated multiple times throughout the study. The frequency of these updates prohibited additional manual mappings, which is why we developed an automated process. Although we did not test the accuracy of the manual process vs. this API-based approach, we suspect a loss of specificity given the amount of additional ICD-standard mapped pairs returned. Should the military proceed with this RDSS, the efficacy of this process should be investigated further. As of December 2019, Comprehend Medical added ICD-10-CM and RxNorm concept mapping [49]. Theoretically, this functionality would obviate the need for the UMLS API in our process.

CONCLUSIONS

This study successfully digitized and mapped the vast majority of AF medical standards to an existing diagnostic terminology and demonstrated one potential use case with positive results. Machine consumable medical standards integrated within existing digital infrastructure and prompted within clinical workflows would remove a significant administrative and cognitive burden from AF providers. The current PDF-based publication of guidelines and standards across a patchwork of information systems is onerous and prone to error. Although we plan to conduct additional validation of the RDSS, easing this access to up-to-date standards and guidelines would likely improve occupational dispositions and the quality of readiness metrics.

PREVIOUS PRESENTATIONS:

(1) Poster presentation at the American Medical Informatics Association (AMIA) Clinical Informatics Conference, Atlanta, Georgia, USA, in May 2019.
(2) Poster presentation at the 2019 Military Health System Research Symposium (MHSRS), Kissimmee, Florida, USA, in August 2019.
(3) Oral presentation at the 7th International Jerusalem Conference on Health Policy, Jerusalem, Israel, in September 2019.

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