Towards automated calculation of evidence-based clinical scores

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Abstract

AIM
To determine clinical scores important for automated calculation in the inpatient setting.

METHODS
A modified Delphi methodology was used to create consensus of important clinical scores for inpatient practice. A list of 176 externally validated clinical scores were identified from freely available internet-based services frequently used by clinicians. Scores were categorized based on pertinent specialty and a customized survey was created for each clinician specialty group. Clinicians were asked to rank each score based on importance of automated calculation to their clinical practice in three categories - "not important", "nice to have", or "very important". Surveys were solicited via specialty-group listserv over a 3-mo interval. Respondents must have been practicing physicians with more than 20% clinical time spent in the inpatient setting. Within each specialty, consensus was established for any clinical score with greater than 70% of responses in a single category and a minimum of 10 responses. Logistic regression was performed to determine predictors of automation importance.
RESULTS
Seventy-nine divided by one hundred and forty-four (54.9%) surveys were completed and 72/144 (50%) surveys were completed by eligible respondents. Only the critical care and internal medicine specialties surpassed the 10-respondent threshold (14 respondents each). For internists, 2/110 (1.8%) of scores were “very important” and 73/110 (66.4%) were “nice to have”. For intensivists, no scores were “very important” and 26/76 (34.2%) were “nice to have”. Only the number of medical history (OR = 2.34; 95%CI: 1.26-4.67; P < 0.05) and vital sign (OR = 1.88; 95%CI: 1.03-3.68; P < 0.05) variables for clinical scores used by internists was predictive of desire for automation.

CONCLUSION
Few clinical scores were deemed “very important” for automated calculation. Future efforts towards score calculator automation should focus on technically feasible “nice to have” scores.

Key words: Automation; Clinical prediction rule; Decision support techniques; Clinical decision support

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Core tip: We report the results of a modified Delphi survey assessing the importance of automated clinical score calculation to practicing internists and intensivists. Although few scores were identified as “very important” for automation, clinicians indicated automated calculation was desired for many commonly used scores. Further studies of the technical feasibility of automating calculation of these scores can help meet these clinicians’ needs.

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INTRODUCTION
Clinical scoring models are ubiquitous in medical literature, but relatively few are routinely used in clinical practice[1]. In general, models have been created to predict clinical outcomes, to perform risk stratification, to aid in clinical decision making, to assess disease severity, and to assist diagnosis. Clinicians have rejected clinical scoring models for many reasons - they lack external validation, they do not provide clinically useful predictions, they require time-intensive data collection, they involve complex mathematical computations, they use arbitrary categorical cut-offs for clinical predictors, they employ imprecise predictor definitions, they require data elements not routinely collected, or they have poor accuracy in real practice[11]. Even among scores accepted by clinicians in clinical practice guidelines[5-9], these same weaknesses can be barriers to consistent, widespread use.

Score complexity is a frequent barrier to manual calculation, especially given the time constraints of clinical practice. The original APACHE score consisted of 34 physiologic variables; data collection and calculation was time-consuming. Subsequent APACHE scoring models have been simplified to include significantly fewer variables, reducing the risk that needed information was not present[6-7]. Other popular scores, such as CHADS2 and HAS-BLED[5,9], have crafted clever mnemonics and point-based scoring systems for easy use at the point-of-care. Despite these simplifications to support manual calculation, many popular and useful clinical scores have been translated to mobile and internet-based calculators for use at the bedside[10-12]. Bringing mobile clinical decision support tools to the point-of-care has demonstrated improvements in clinical decision-making[13], however these tools remain isolated from the clinical data present in the Electronic Health Record (EHR).

In 2009, Congress passed the HITTECH act, which aimed to stimulate EHR adoption by hospitals and medical practices. Consequently, as of 2014, 96.9% of hospitals have a certified EHR, and 75.5% have basic EHR capabilities[14]. Concurrent with EHR adoption, there has been a renewal of the emphasis on improving quality and safety and practicing evidence-based medicine[15]. Integration of useful evidence-based clinical score models into the EHR with automated calculation based on real-time data is a logical step towards continuing to improve patient care.

The goal of this study is to identify the clinical scores recognized by clinicians as important to the scope of their clinical practice. This information will be invaluable for prioritizing further research into methods of score automation and delivery to the right provider for the right patient in the appropriate clinical context.

MATERIALS AND METHODS
This study was reviewed and approved by the Institutional Review Board at Mayo Clinic in Rochester, MN. This study utilized a modified Delphi methodology to seek a consensus of clinical score calculators important in clinical practice for each represented hospital-based specialty. The Delphi methodology is an iterative process used in studies for the purpose of arriving at a consensus opinion among content experts[17]. This approach is often utilized when there is incomplete knowledge about a problem or phenomenon and expert judgment is needed for guidance, such as clinical guideline creation[18]. In general, the Delphi methodology consists of a series of rounds where participating content experts are asked to respond to results from the previous round[16]. The first round, which serves as a brainstorming session to generate a list of topics for future rounds, can be replaced
Systematic collection of online clinical score calculators

Branching survey logic mapped score calculators to applicable specialties

Academic and community based clinicians

Branching survey logic mapped score calculators to applicable specialties

Academic and community based clinicians

Table 1  Description of modified Delphi methodology

| Delphi round 1 | Systematic collection of online clinical score calculators |
|---------------|----------------------------------------------------------|
| Delphi round 2 | Survey development                                       |
| Survey        | Branching survey logic mapped score calculators to applicable specialties |

Table 2  Survey respondent characteristics

| Completion rate | n of Scores |
|-----------------|-------------|
| Anesthesia      | 2/5 (40%)   | 49  |
| Cardiology      | 1/1 (100%)  | 37  |
| Critical care   | 14/23 (61%) | 75  |
| Dermatology     | 0/0         | 1   |
| Emergency medicine | 4/6 (67%)   | 62  |
| Family medicine | 2/5 (40%)   | 107 |
| Gastroenterology | 3/3 (100%)  | 17  |
| Hematology      | 1/1 (100%)  | 5   |
| Infectious disease | 2/2 (100%) | 2   |
| Internal medicine | 14/25 (56%)| 109 |
| Nephrology      | 1/1 (100%)  | 6   |
| Neurology       | 0/1 (0%)    | 23  |
| OB/GYN          | 1/1 (100%)  | 1   |
| Oncology        | 1/2 (50%)   | 5   |
| Orthopedics     | 0/0         | 3   |
| Pediatric       | 7/13 (54%)  | 25  |
| Pulmonology     | 4/6 (67%)   | 17  |
| Surgery         | 2/3 (67%)   | 66  |

by a systematic review in many situations\(^{[16]}\). The Delphi process used by this study is shown in Table 1.

The list of clinical calculators for the first Delphi round was generated by a prior study performed by our group\(^{[18]}\). In brief, 176 externally validated clinical scores were identified in calculator form as internet-based services. While this list of clinical calculators is not all-inclusive, it represents all calculators found on popular medical reference web portals (such as Medscape\(^{[11]}\) and UpToDate\(^{[19]}\) and websites aggregating commonly used clinical calculators\(^{[10-12]}\). Each calculator was mapped to clinician pertinent specialties for the purpose of generating a customized survey in the next Delphi round. A survey was created in REDCap\(^{[20]}\) utilizing branching logic to ensure that each responding clinician would only be presented a subset of clinical scores pertinent to their specialty. Score-specialty assignment was verified by non-study associated clinicians at our institution in each represented specialty.

In the second Delphi round, the survey was distributed to clinicians in academic and community settings throughout the United States via specialty group LISTSERV’s. Only practicing clinicians with greater than 20% of their clinical time spent in the inpatient setting were eligible to serve as content experts for this Delphi round. Respondents were asked to assess the importance of automatic calculation of each clinical score to their clinical practice. Each survey item could be ranked on a three-point Likert scale - “not needed”, “nice to have”, or “very important”. Consensus for each score was defined by greater than 70% of clinicians in each specialty rating the score in any category. A target of at least 10 experts from each represented specialty is recommended to attain consensus based on established Delphi methodology\(^{[16]}\); repeated solicitations were sent to underrepresented specialty groups for 3 mo to maximize participation. Descriptive statistics were obtained for each score, grouped by specialty. Variables for each clinical score were categorized by type of clinical information. Logistic regression was performed to characterize clinical score features predictive of automation importance. Statistical analysis was performed with R version 3.3.1\(^{[21]}\).

RESULTS

One hundred forty-four surveys were initiated by respondents. Seventy-nine in one hundred and forty-four (54.9%) were completed and 72/144 (50.0%) were completed by eligible respondents based on based on level of experience and percent of practice spent in the inpatient setting. Only two specialties, internal medicine and critical care medicine, surpassed the 10-respondent threshold with 14 complete responses each (Table 2). Among intensivists, only 2/110 (1.8%) were deemed very important for automation, while 73/110 (66.4%) were “nice to have”. Among intensivists, no scores were deemed very important for automation, however 26/76 (34.2%) were “nice to have” if automation was possible. A summary of score ratings for both specialties can be found in Table 3. Suggestions of missing scores included Center criteria, Ottawa knee/ankle/foot rules, estimated free water deficit, opioid risk assessment tool, Bishop score, and several screening questionnaires. Too few scores were ranked as “very important” for automation by either specialty to perform regression, however logistic regression was performed on a composite outcome of scores deemed “nice to have” + “very important” (Table 4).

DISCUSSION

This study assesses clinicians’ perspectives on the importance of automating specific clinical scores within the EHR for their clinical practice. We chose a modified Delphi methodology because of our previous study’s thoroughness in identifying clinical score calculators across multiple specialty domains and to reduce respondent survey burden. The primary advantage of using a modified Delphi methodology in this study is the ability to capture the valuation of multiple scores by clinicians across varying specialties. The primary disadvantage to this methodology is the recruitment of appropriate content.
Table 3  Summary of importance of automation of specified clinical scores ranked by critical care and internal medicine physicians

| Score name | Year of creation | n of variables | Very important | Very important or nice to have |
|------------|------------------|----------------|----------------|-------------------------------|
| Critical care | 1985 | 15 | 9/14 (64.3%) | 12/14 (85.7%) |
| APACHE II | 2001 | 9 | 7/11 (63.6%) | 9/11 (81.8%) |
| SNAP II | 1998 | 5 | 7/12 (58.3%) | 10/12 (83.3%) |
| NRDS scoring system | 1970 | 5 | 7/12 (58.3%) | 9/12 (75%) |
| Post-anesthetic recovery score | 1997 | 4 | 7/12 (58.3%) | 8/12 (66.7%) |
| Rotterdam score | 1993 | 27 | 7/12 (58.3%) | 9/12 (75%) |
| SNAP | 2003 | 30 | 7/12 (58.3%) | 9/12 (75%) |
| SNAP-PE | 2003 | 12 | 7/12 (58.3%) | 9/12 (75%) |
| Wells criteria for DVT | 1998 | 9 | 7/12 (58.3%) | 10/12 (83.3%) |
| Wells criteria for PE | 2008 | 7 | 6/11 (54.5%) | 8/11 (72.7%) |
| PAWS | 1993 | 5 | 6/12 (50%) | 8/12 (66.7%) |
| CRIB | 2003 | 5 | 6/12 (50%) | 8/12 (66.7%) |
| CRIB II | 2002 | 7 | 6/12 (50%) | 8/12 (66.7%) |
| MESS | 1999 | 13 | 3/6 (50%) | 4/6 (66.7%) |
| SAPS II | 1993 | 16 | 5/10 (50%) | 7/10 (70%) |
| TISS | 2006 | 3 | 5/11 (45.5%) | 8/11 (72.7%) |
| Children's coma score | 1987 | 9 | 4/9 (44.4%) | 6/9 (66.7%) |
| PRISM score | 1984 | 16 | 3/7 (42.9%) | 4/7 (57.1%) |
| CURB-65 | 2003 | 5 | 5/12 (41.7%) | 8/12 (66.7%) |
| SCORETEN scale | 2000 | 6 | 5/12 (41.7%) | 9/12 (75%) |
| MEWS score | 2005 | 5 | 4/10 (40%) | 6/10 (60%) |
| Rockall score | 2008 | 11 | 3/8 (37.5%) | 5/8 (62.5%) |
| TRIOS scale | 2001 | 4 | 3/8 (37.5%) | 5/8 (62.5%) |
| Geneva score for PE | 2006 | 9 | 4/11 (36.4%) | 7/11 (63.6%) |
| Injury Severity Score | 1974 | 6 | 4/11 (36.4%) | 8/11 (72.7%) |
| Lung Injury score | 1988 | 5 | 4/11 (36.4%) | 8/11 (72.7%) |
| MPM - admission | 1993 | 14 | 4/11 (36.4%) | 6/11 (54.5%) |
| MPM - 24-48-72 | 1993 | 14 | 4/11 (36.4%) | 6/11 (54.5%) |
| LODS score | 1996 | 12 | 3/9 (33.3%) | 7/9 (77.8%) |
| MEDS score | 2003 | 10 | 3/9 (33.3%) | 6/9 (66.7%) |
| MESS score | 1997 | 5 | 4/12 (33.3%) | 7/12 (58.3%) |
| Parsonnet Score | 1989 | 14 | 4/12 (33.3%) | 7/12 (58.3%) |
| Pediatric coma scale | 1988 | 3 | 2/6 (33.3%) | 3/6 (50%) |
| RAPS | 1987 | 5 | 3/9 (33.3%) | 7/9 (77.8%) |
| Surgical Appar score | 2007 | 3 | 4/12 (33.3%) | 8/12 (66.7%) |
| ASCOT score | 1990 | 8 | 4/13 (30.8%) | 6/13 (46.2%) |
| MELD score | 2001 | 4 | 4/13 (30.8%) | 12/13 (92.3%) |
| PI2 | 2003 | 8 | 2/7 (28.6%) | 5/7 (71.4%) |
| SWIFT score | 2008 | 6 | 2/7 (28.6%) | 4/7 (57.1%) |
| Clinical Pulmonary Infection Score | 1991 | 8 | 3/11 (27.3%) | 9/11 (81.8%) |
| MPM-24 h | 1988 | 15 | 3/11 (27.3%) | 6/11 (54.5%) |
| Child-Pugh Score | 1973 | 5 | 3/12 (25%) | 11/12 (91.7%) |
| Decaf score | 2012 | 5 | 2/8 (25%) | 4/8 (50%) |
| ONTARIO score | 1995 | 6 | 2/8 (25%) | 4/8 (50%) |
| AKICS score | 2007 | 8 | 3/13 (23.1%) | 7/13 (53.8%) |
| AVPU scale | 2004 | 4 | 2/9 (22.2%) | 6/9 (66.7%) |
| PERC rule for PE | 2001 | 7 | 2/9 (22.2%) | 6/9 (66.7%) |
| RITE score | 1988 | 6 | 2/9 (22.2%) | 6/9 (66.7%) |
| BISAP score for pancreatitis mortality | 2008 | 5 | 2/10 (20%) | 4/10 (40%) |
| Bleeding risk score | 2007 | 4 | 2/10 (20%) | 6/10 (60%) |
| Clinical asthma evaluation score | 1972 | 5 | 2/10 (20%) | 6/10 (60%) |
| PIRO score | 2009 | 8 | 2/10 (20%) | 7/10 (70%) |
| ABC score for massive transfusion | 2009 | 4 | 2/11 (18.2%) | 6/11 (54.5%) |
| ACIS score | 1981 | 4 | 2/11 (18.2%) | 7/11 (63.6%) |
| MOD score | 1995 | 7 | 2/11 (18.2%) | 8/11 (72.7%) |
| MPM - admission | 1988 | 10 | 2/11 (18.2%) | 6/11 (54.5%) |
| sPESI | 2010 | 8 | 2/11 (18.2%) | 7/11 (63.6%) |
| ABC score | 2008 | 8 | 2/12 (16.7%) | 5/12 (41.7%) |
| CRUSADE score | 2009 | 8 | 2/12 (16.7%) | 6/12 (50%) |
| Pediatric trauma score | 1988 | 6 | 1/6 (16.7%) | 2/6 (33.3%) |
| LRINEC Score for Necrotizing STI | 2004 | 5 | 1/8 (12.5%) | 4/8 (50%) |
| PanC 3 score | 2007 | 3 | 1/8 (12.5%) | 3/8 (37.5%) |
| Pancreatitis outcome score | 2007 | 7 | 1/8 (12.5%) | 3/8 (37.5%) |
| TASH score | 2006 | 7 | 1/8 (12.5%) | 4/8 (50%) |

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| Measure                                | Year  | Score | Percent | Percent | Percent |
|----------------------------------------|-------|-------|---------|---------|---------|
| POSSUM score                           | 1991  | 18    | 1/9 (11.1%) | 3/9 (33.3%) |
| Revised Trauma score                   | 1981  | 3     | 1/9 (11.1%) | 5/9 (55.6%) |
| 24 h ICU trauma score                  | 1992  | 4     | 1/10 (10%) | 7/10 (70%) |
| HIT Expert Probability Score           | 2010  | 11    | 1/11 (9.1%) | 6/11 (54.5%) |
| Bronchiectasis severity index          | 2014  | 10    | 1/12 (8.3%) | 4/12 (33.3%) |
| Oxygenation index                      | 2005  | 3     | 1/15 (7.7%) | 7/15 (53.8%) |
| CT severity index                      | 1990  | 1     | 0/12 (0%) | 6/12 (50%) |
| Glasgow coma scale                     | 1974  | 3     | 0/13 (0%) | 10/13 (76.9%) |
| SOFA                                   | 2001  | 6     | 0/13 (0%) | 8/13 (61.5%) |
| **Internal medicine**                  |       |       |         |         |
| Wells criteria for DVT                 | 2006  | 9     | 10/14 (71.4%) | 13/14 (92.9%) |
| Wells criteria for PE                  | 1998  | 7     | 10/14 (71.4%) | 13/14 (92.9%) |
| CHA2DS2-VASc                          | 2010  | 7     | 9/14 (64.3%) | 13/14 (92.9%) |
| TIMI risk score for UA/NSTEMI           | 2000  | 7     | 9/14 (64.3%) | 13/14 (92.9%) |
| TIMI risk score for STEMI              | 2000  | 9     | 9/14 (64.3%) | 13/14 (92.9%) |
| CURB-65                                | 2003  | 5     | 8/14 (57.1%) | 13/14 (92.9%) |
| STESS score                            | 2008  | 4     | 8/14 (57.1%) | 13/14 (92.9%) |
| Duke criteria for IE                   | 1994  | 8     | 6/13 (46.2%) | 12/13 (92.3%) |
| PESI                                   | 2006  | 11    | 7/12 (58.3%) | 11/12 (91.7%) |
| Revised cardiac risk index for pre-operative | 1999 | 6     | 7/12 (58.3%) | 11/12 (91.7%) |
| SOFA                                   | 2001  | 6     | 6/12 (50%) | 11/12 (91.7%) |
| ABCD2 score                            | 2006  | 5     | 5/12 (41.7%) | 11/12 (91.7%) |
| Charlson Comorbidity index             | 1987  | 1     | 2/12 (16.7%) | 11/12 (91.7%) |
| PERC rule for PE                       | 2001  | 7     | 5/11 (45.5%) | 10/11 (90.9%) |
| sPESI                                  | 2010  | 8     | 4/11 (36.4%) | 10/11 (90.9%) |
| MOD score                              | 1995  | 7     | 3/11 (27.3%) | 10/11 (90.9%) |
| MPM - 24 h                             | 1988  | 15    | 4/10 (40%) | 9/10 (90%) |
| MPM - admission                        | 1988  | 10    | 3/10 (30%) | 9/10 (90%) |
| MEDS score                             | 2003  | 10    | 2/10 (20%) | 9/10 (90%) |
| PIRO score                             | 2009  | 8     | 1/10 (10%) | 9/10 (90%) |
| SAPS II                                | 1993  | 16    | 9/44 (44.4%) | 8/9 (88.9%) |
| SWIFT score                            | 2008  | 6     | 2/8 (25%) | 7/8 (87.5%) |
| Panc s3 score                          | 2007  | 3     | 1/8 (12.5%) | 7/8 (87.5%) |
| APACHE II                              | 1985  | 15    | 9/14 (64.3%) | 12/14 (85.7%) |
| Parsonson score                         | 1989  | 14    | 8/14 (57.1%) | 12/14 (85.7%) |
| HIT Expert Probability Score           | 2010  | 11    | 6/14 (42.9%) | 12/14 (85.7%) |
| Ramson's criteria                      | 1974  | 11    | 6/14 (42.9%) | 12/14 (85.7%) |
| TRIOS score                            | 2001  | 4     | 3/7 (42.9%) | 6/7 (85.7%) |
| 4Ts Score                              | 2006  | 5     | 5/14 (35.7%) | 12/14 (85.7%) |
| Framingham coronary heart disease risk score | 1998 | 7     | 5/14 (35.7%) | 12/14 (85.7%) |
| 30 d PCI readmission risk              | 2013  | 10    | 2/7 (28.6%) | 6/7 (85.7%) |
| Glasgow coma scale                     | 1974  | 3     | 9/11 (81.8%) | 11/11 (100%) |
| Modified NIH Stroke Scale              | 2001  | 9     | 7/13 (53.9%) | 11/13 (84.6%) |
| King's College Criteria for Acetaminophen Toxicity | 1989 | 6     | 4/12 (33.3%) | 10/12 (83.3%) |
| Glasgow-Blatchford Bleeding score      | 2000  | 9     | 3/12 (25%) | 10/12 (83.3%) |
| ATRIA bleeding risk score              | 2011  | 6     | 2/12 (16.7%) | 10/12 (83.3%) |
| Glasgow Alcoholic hepatitis score      | 2004  | 5     | 5/11 (45.5%) | 9/11 (81.8%) |
| MEWS score                             | 2006  | 6     | 4/11 (36.4%) | 9/11 (81.8%) |
| Hemorrhages score                      | 2006  | 11    | 2/11 (18.2%) | 9/11 (81.8%) |
| Decaf score                            | 2012  | 5     | 4/10 (40%) | 8/10 (80%) |
| MPMII - admission                      | 1993  | 14    | 4/10 (40%) | 8/10 (80%) |
| MPMII - 24-48-72                       | 1993  | 14    | 4/10 (40%) | 8/10 (80%) |
| Malnutrition universal screening tool (MUST) | 2004 | 3     | 2/10 (20%) | 8/10 (80%) |
| ASTRAL score                           | 2012  | 6     | 1/10 (10%) | 8/10 (80%) |
| GRACE ACS                              | 2006  | 12    | 1/10 (10%) | 8/10 (80%) |
| CHAID2                                 | 2001  | 5     | 7/14 (50%) | 11/14 (78.6%) |
| Multidimensional frailty score         | 2014  | 9     | 7/14 (50%) | 11/14 (78.6%) |
| Geneva score for PE                    | 2006  | 9     | 3/9 (33.3%) | 7/9 (77.8%) |
| Pittsburg knee rules                   | 1994  | 3     | 3/9 (33.3%) | 7/9 (77.8%) |
| Mayo scoring system for assessment of ulcerative colitis activity | 2005  | 4     | 1/9 (11.1%) | 7/9 (77.8%) |
| 4-yr mortality prognostic index       | 2006  | 12    | 1/9 (11.1%) | 7/9 (77.8%) |
| Rockall score                          | 2008  | 11    | 1/9 (11.1%) | 7/9 (77.8%) |
| SHARP scoring system                   | 2004  | 9     | 1/9 (11.1%) | 7/9 (77.8%) |
| HAS-BLED                               | 2010  | 12    | 5/13 (38.5%) | 10/13 (76.9%) |
| ATRIA stroke risk score                | 2013  | 7     | 3/12 (25%) | 9/12 (75%) |
| Euroscore                              | 1999  | 17    | 1/8 (12.5%) | 6/8 (75%) |
| Renal risk score                       | 2011  | 6     | 1/8 (12.5%) | 6/8 (75%) |
| ROSE risk score                        | 1996  | 7     | 1/8 (12.5%) | 6/8 (75%) |
| LRINEC Score for Necrotizing STI       | 2004  | 5     | 3/11 (27.3%) | 8/11 (72.7%) |
Clinical scores can play important roles in the clinical decision-making algorithms used daily by clinicians. Mobile and internet-based clinical calculators have made potentially workflow disrupting standalone smartphone or calculation within the EHR eliminates the need for these entry. Automated retrieval of variables required for score calculation within the EHR eliminates the need for these daily clinical score calculations easier, however the use of these standalone technologies does not reduce the time and effort required for manual data retrieval and entry. Automated retrieval of variables required for score calculation within the EHR eliminates the need for these potentially workflow disrupting standalone smartphone or web applications. Additionally, automated calculation of clinical scores provides a mechanism to improve care standardization, to facilitate adherence to evidence-based practice and clinical guidelines, and to save time. However, just as clinicians have rejected many clinical scores for routine usage, our study found that clinicians did not appraise most clinical scores as “very important” for automation.

The clinical score variables examined in this study spanned several broad categories - demographic information, laboratory values, medical history elements, clinical examination findings, clinical judgments, and even other clinical scores. Some categories, such as laboratory values or medical history elements, may require more time-intensive data retrieval compared to others. We predicted that commonly used scores with cognitively

| Score Name | Year | Users | Approval | Time-savings |
|------------|------|-------|----------|--------------|
| Bleeding risk score | 2007 | 4 | 2/11 (18.2%) | 8/11 (72.7%) |
| CT severity index | 1990 | 1 | 1/11 (9.1%) | 8/11 (72.7%) |
| SCORETEN scale | 2000 | 6 | 7/14 (50%) | 10/14 (71.4%) |
| REMS | 2004 | 7 | 2/7 (28.6%) | 5/7 (71.4%) |
| Mayo CABG risk of inpatient death after MI | 2007 | 7 | 1/7 (14.3%) | 5/7 (71.4%) |
| Mayo PCI risk of inpatient MACE | 2007 | 7 | 1/7 (14.3%) | 5/7 (71.4%) |
| QMII score | 2001 | 11 | 1/7 (14.3%) | 5/7 (71.4%) |
| MELD score | 2001 | 4 | 0/14 (0%) | 10/14 (71.4%) |
| Nexus criteria for C-spine imaging | 1970 | 5 | 4/10 (40%) | 7/10 (70%) |
| Birmingham nutritional risk score | 1995 | 7 | 2/10 (20%) | 7/10 (70%) |
| Canadian CT head rule | 2001 | 9 | 2/10 (20%) | 7/10 (70%) |
| ACLS score | 1981 | 4 | 1/10 (10%) | 7/10 (70%) |
| San Francisco syncope rule | 2004 | 5 | 1/10 (10%) | 7/10 (70%) |
| Mannheim peritonitis index | 1993 | 7 | 6/13 (46.2%) | 9/13 (69.2%) |
| HADO score | 2006 | 4 | 3/9 (33.3%) | 6/9 (66.7%) |
| CARE score | 2001 | 3 | 1/9 (11.1%) | 6/9 (66.7%) |
| ICH score | 2001 | 5 | 1/9 (11.1%) | 6/9 (66.7%) |
| Adult appendicitis score | 2014 | 8 | 6/14 (42.9%) | 9/14 (63.4%) |
| IMPACT score | 2008 | 11 | 6/14 (42.9%) | 9/14 (63.4%) |
| CRUSADE score | 2009 | 8 | 4/14 (28.6%) | 9/14 (63.4%) |
| PORT/PSI score | 1997 | 20 | 2/14 (14.3%) | 9/14 (63.4%) |
| CIWA-Ar | 1989 | 10 | 1/14 (7.1%) | 9/14 (63.4%) |
| LODS score | 1996 | 12 | 3/8 (37.5%) | 5/8 (62.5%) |
| OESIL risk score | 2003 | 4 | 2/8 (25%) | 5/8 (62.5%) |
| QRISK2 | 2010 | 14 | 2/8 (25%) | 5/8 (62.5%) |
| Qstroke score | 2013 | 15 | 2/8 (25%) | 5/8 (62.5%) |
| RRIE score | 1997 | 6 | 2/8 (25%) | 5/8 (62.5%) |
| EGOSYS score | 1997 | 8 | 1/12 (8.3%) | 5/8 (62.5%) |
| EHMRG | 2012 | 10 | 1/12 (8.3%) | 5/8 (62.5%) |
| FOUR score | 2005 | 4 | 1/12 (8.3%) | 5/8 (62.5%) |
| Pancreatitis outcome score | 2007 | 7 | 1/12 (8.3%) | 5/8 (62.5%) |
| Prostate cancer prevention trial risk calculator | 1993 | 6 | 6/13 (46.2%) | 8/13 (61.5%) |
| Alvarado score for acute appendicitis | 1986 | 8 | 5/13 (38.5%) | 8/13 (61.5%) |
| DRAGON score | 2012 | 6 | 1/10 (10%) | 6/10 (60%) |
| Bronchiectasis severity index | 2014 | 10 | 3/14 (21.4%) | 8/14 (57.1%) |
| New Orleans head CT rule | 2000 | 8 | 1/7 (14.3%) | 4/7 (57.1%) |
| POSSUM score | 1991 | 18 | 1/7 (14.3%) | 4/7 (57.1%) |
| Child-Pugh Score | 1973 | 5 | 0/14 (0%) | 8/14 (57.1%) |
| Lung Injury score | 1988 | 5 | 4/9 (44.4%) | 5/9 (55.6%) |
| AVPU scale | 2004 | 4 | 2/9 (22.2%) | 5/9 (55.6%) |
| Gupta perioperative cardiac risk | 2011 | 5 | 2/9 (22.2%) | 5/9 (55.6%) |
| HEART score | 2008 | 5 | 1/9 (11.1%) | 5/9 (55.6%) |
| IgA nephropathy score | 2006 | 8 | 5/14 (35.7%) | 7/14 (50%) |
| ABIC score | 2008 | 4 | 4/14 (28.6%) | 7/14 (50%) |
| CAMBS score | 1993 | 4 | 4/14 (28.6%) | 7/14 (50%) |
| GAP risk assessment score | 2012 | 4 | 2/8 (25%) | 4/8 (50%) |
| BISAP score for pancreatitis mortality | 2008 | 5 | 2/10 (20%) | 5/10 (50%) |
| ONTARIO score | 1995 | 6 | 1/8 (12.5%) | 4/8 (50%) |
| JAMA kidney failure risk equation | 2011 | 7 | 4/13 (30.8%) | 5/13 (38.5%) |
demanding information extraction would be more desirable for automation. However, our regression model did not explicitly include variables representing time-required for data collection or data entry for any score - the key efficiencies gained through automated calculation. Instead, we used the number of variables in the score and variable categorization as surrogates to account for these cognitively demanding tasks. No association between the number of clinical variables and desirability of automation was found for the internal medicine or critical care specialties. Only two scores met the threshold for being "very important" for automation by internists - Wells criteria for DVT[22] (10/13, 71.4%) and PE[23] (10/13, 71.4%). Although many more scores were deemed "nice to have" by both specialties, regression analysis only identified the number of medical history variables (OR = 2.34; 95%CI: 1.26-4.67; P < 0.05) and vital sign variables (OR = 1.88; 95%CI: 1.03-3.68; P < 0.05) as predictive of desirability of automation among internists. The time and cognitive workload of performing manual chart review for unknown aspects of the medical history may explain this finding; several tools have been created to meet this clinical need.[25,26]

The time-benefit gained from reduced workflow disruption may be more apparent in scores pertaining to common clinical scenarios, such as sepsis. During the survey period, the SOFA score was integrated into the operational definition of sepsis[17], likely affecting the valuation of automated calculation by some specialties. The prospective benefit of automated calculation of this and similar scores is readily apparent; one study comparing automated and manual calculation of the SOFA score[27] found an average time-savings of about 5 min per calculation attained by automation.[28] Extrapolated to a unit of 12 patients, up to one hour of work could be saved daily through automated calculation of this single score. More complex scores may have even greater-time-savings.

This study has several limitations. First, the survey items may not represent all pertinent clinical scores in all specialties surveyed. We did consult with local experts in each specialty to review the completeness of the list of clinical scores. Additionally, respondents were solicited for additional scores to be considered. Many of the suggestions represented either diagnostic criteria (Centor criteria or Ottawa foot/ankle/knee rules) or diagnostic questionnaires (PHQ-9, CAGE, AUDIT) - all are useful clinical tools but not amenable to automated score calculation.

Second, the responding experts may not represent the viewpoints of all clinicians in each field. We sought a heterogeneous group of clinicians within each specialty, representing both academic and community hospital settings nationwide. However, only 6 internists and 6 intensivists that completed our survey volunteered their hospital’s name; all were academic health centers. This potential response bias would favor clinical scores used primarily in academic settings, a concern that has been raised for certain scores.[29] Additionally, survey response rate was low despite multiple solicitations targeting lesser represented specialties, a likely reflection of physician survey fatigue.

Third, consensus was not reached for most clinical scores for either specialty. Since both specialties had a large number of pertinent clinical scores, it would be expected that consensus could not be reached for many scores. When exploring the programmability of specific clinical scores, researchers may be more inclined to investigate methods for automated calculation of “nice to have” scores that are highly programmable to meet the needs of these clinicians. Further investigation is needed to assess the overall programmability of each clinical score calculator within modern electronic medical record systems utilizing commonly available clinical data and information retrieval techniques.

In conclusion, Internal medicine and critical care physicians assessed evidence-based clinical scores on the importance of automated calculation to their clinical practice. Very few clinical scores were deemed “very important” to automate, while many were considered “nice to have”. In order to prioritize automating calculation of some of these “nice to have” clinical scores, further research is needed to evaluate the feasibility of programming each score in the electronic medical record.

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COMMENTS

Background
Numerous clinical scores have been created, but it is not known which scores may be important for automated calculation within the electronic medical record.

Research frontiers
Automated calculation of important scores can reduce physician's cognitive workload and facilitate practice guideline adherence.

Innovations and breakthroughs
This study is a comprehensive assessment of importance of automating calculation of clinical scores in the inpatient setting.

Applications
In this study, clinicians identified specific clinical scores as desirable for automated calculation. This information can guide future research on techniques to automate these scores to meet clinician's needs.

Peer-review
The authors investigating scoring systems of evidence for clinical application. The aim was clear and results were useful.

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