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Hospital Status Admission Determination

The Use of Boolean Logic, Set Theory, and Information Theory to Improve Accuracy

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ABSTRACT

Purpose: To evaluate methods of logic, set theory, and information theory in developing a conceptual framework that would be useful in an educational process as well as in developing a consistent and rational method for hospital status determination.

Objectives: To implement these methods on a daily basis in interaction with nurse case managers, physicians, and in documentation of the process.

Primary practice setting: A tertiary private, not-for-profit institution within the department of case management and utilization review.

Findings: These methods were well accepted by those involved in the decision process and allowed a Case Management Assignment Protocol to function well in the hospital environment with a low level of disagreement and conflict.

Conclusions: Medical information can be processed effectively with conceptual models of logic and information theory. The used commercial screening systems are described well by set theory and are intersecting sets of patient variables and characteristics.

Implications for case management practice: These methods can be used in educational processes in practice settings apart from those using the Case Management Assignment Protocol. It provides a basis for evaluation of patients' presentations that use important factors such as clinical uncertainty, patient specific data, and reference to preexisting admission criteria.

Key words: *Boolean, case management, case management assignment protocol, entropy, hospital status determination, information theory, logic, set theory.*

An important role of a hospital Utilization Review and Care Management Department is to have hospital admission status performed promptly and accurately. This reports the experience of an institution that has used the Case Manager Assignment Protocol (CMAP; Michelman et al., 2005). This protocol delegates the determination of the hospital admission to the staff of the Utilization Review and Case Management Department with the consent of the hospital medical staff and recorded in the hospital and medical staff policies and procedures and medical staff bylaws. Each determination is ultimately signed by the attending physician and becomes a part of the medical record.

Early experience prior to the institution of the CMAP suggested that individual attending physicians were not adept at assigning proper status. Without specific training, it was found that the accuracy of attending physician determination in cases that required review was equal to essentially a chance determination. The reason is that an accurate status determination requires a fairly detailed knowledge of the available screening systems, that certain conditions such as congestive heart failure or pneumonia may indeed not satisfy inpatient criteria solely on the basis of diagnoses but require additional physiologic abnormalities to assess severity. To facilitate education and decision making, it was found that systems applicable to logical or mathematical thought would be helpful in communicating the decision process of what would otherwise be interpreted as arbitrary or inconsistent (see Table 1).

This protocol was instituted at a private, tertiary, not-for-profit hospital for all admissions for greater than 5 years. The circumstances that enabled a smooth utilization of this protocol was stable leadership and staff of the Utilization Review and Care Management department and the utilization of one on-site physician advisor, an active Utilization Review

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TABLE 1
Factors in Status Determinations

Patients' rights to medical treatment
Providers' obligation to provide treatment
Adherence to standards of screening systems
Integration of local standards of care and integration with Utilization Review Committee
Patient population and demographics significant factor
Reviews by administrative agencies require consistent transparent system
Status determinations in a complex system requiring a binary decision—inpatient/outpatient

TABLE 2
Hospital Secondary Review System

Medical literature and medical syndrome based
Considers natural course of disease, prognosis, and treatment
A priori but requires specific elements of individual patient characteristics to be present
Assesses multiple parameters of risk and comprehensive need for hospital admission
Specifically useful in uncommon syndromes and presentations
Recognizes early rapidly progressive organ dysfunction
Uses critical analysis of illness and treatment system intersections
Emphasizes provider physician documentation

Committee, and the use of an off-site physician advisor for off hours determination. The institution and development of a hospitalist system facilitated review by improving documentation and recognition of the noninpatient status determinations in medical treatment and discharge planning.

At this institution, all efforts were made to correctly assume the obligation of these status determinations that previously would be made by the attending physician. Every effort was made in each case to thoroughly evaluate the data and the physician documentation and attempt to use the commercial screening system to make the status determination. If there was evidence that the admission be more suitable for inpatient status, rather than outpatient, then a dialogue with the physician adviser was initiated. The available data that are reviewed were often available through the hospital information system that contained physicians' documentation, and reports of ancillary studies as well as real-time physiologic data. After assessment of the data and ensuring that the case did not optimally fit the screening system was the secondary review system accessed.

The Secondary Review system is unique to the institution that was used to facilitate the use of the CMAP (see Table 2). It was first utilized in specialized training of the nurse case managers to assist in the optimal review of the documentation of the admission. The emphasis was that all relevant data were accessed from the medical record and the data properly interpreted. Emphasis was on the abnormalities that were relevant to the current problem as it became apparent that in a population of patients with well-documented prior admissions and procedures that history could potentially overshadow the events that precipitated the admission. Conceptual methods such as the patient's conditions in terms of rapidity and extent of change from baseline, risk of adverse outcome, treatment required, diagnostic uncertainty, and its change over time with additional medical information are assessed.

The Secondary Review system is an a priori system in that it categorizes what could be an idealized set of conditions or elements that define an inpatient, prior to the review of that particular patient. The term a priori is used in the context that it is independent of experience with a particular patient. The subsequent determination is based upon that particular patient and thus becomes a posteriori. The a priori system is well characterized in logic, philosophy, and theological discourse (Lewis, 1987; Russell, 2011; Soloveitchik, 1983).

An important issue in status determination is the correct way of acknowledging that medical providers have an obligation to resolve medical uncertainty, which is often described as a "concern" relating to a potential diagnosis and that hospitalization is required. There can be a difference between what a treating physician may consider a legitimate concern and what may be considered an appropriate admission by a screening system.

A logical method that could be directed at this concept of concern is to consider whether the assessment is a priori, but it is not supported by the individual patient's circumstances. An example would be: For all elderly patients who have syncope, there is a concern that this represents critical aortic stenosis or potentially fatal arrhythmia. Russell (2011) describes such statements as necessary propositions that cannot be false. Should there be experiential evidence that this particular patient has a substantiated risk for this outcome then this concern is a posteriori and is

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strengthened and more readily justifies the treatment. The decision to admit is strengthened when the documentation clearly delineates the adverse risk related to the particular patient and any supporting evidence that has been evaluated.

At times, this concept is straightforward and is associated with conditions that can be rapidly evaluated and is readily able to be risk-stratified, for example, the evaluation of chest pain (Anderson et al., 2007). This might be referred to as a "rule out" category of admission and requires a well-defined sequence of testing. More difficult is the presentation of conditions that do not appear to be life threatening, have stable vital signs, and are not clearly a significant change from baseline function. Factors such as availability of outpatient or primary care treatment and family and physician dynamics are often operative. These patients often will neither meet standard inpatient criteria, nor will they be designated as inpatients in a robust secondary review system.

Boolean Logic, Set Theory, and Logic Gates

There is a potential contradiction in patient-oriented medical care and that of making a definitive assessment of a process with many variables. In fact, the categories of admission, inpatient, observation, or ambulatory are well represented by a Venn diagram (see Figure 1). A potential solution to this problem that was developed was based upon Boolean Logic, which is consistent with a binary system of yes/no, true/false, or positive/negative designation to make a status determination of inpatient/outpatient. This binary system is used in Boolean Logic and Algebra, where mathematical functions can be written with the variables being only 0 or 1.

George Boole's treatise (2005), *An Investigation of the Laws of Thought*, attempted to express in a symbolic notation human thought (see Table 3). It became apparent that one of the major screening systems could be evaluated in terms of Set Theory and Boolean Logic. These systems are an intersection of two systems: one composed of physiologic abnormalities and the other of treatment parameters (see Figure 2). The intersection of two systems in Boolean Logic is that of an "AND" systems. This would be analogous in an electronic logic gate requiring both gates to be open to complete the circuit. Boolean Logic can be represented as truth tables, electronic circuits, or Venn diagrams (Whitsitt, 1961; see Figure 3). The first column of figures indicates the "AND" function or intersection of sets and the second column indicates the "OR" function or union of sets. The third and fourth columns represent other logical propositions. For example, the third column would be a logical proposition that is false when "x" is true and "y" is false but is true for any other combination. This is not applicable to status determinations when the statement must be true when both are true or rarely when one is true. The symbols are standard for Boolean Algebra propositional functions (Brown, 2003).

This concept is useful in graphically illustrating the relationship of the various sets that are defined by their characteristics (see Table 4, see Figure 4). *X* is

TABLE 3
What Is Boolean Algebra and Logic?

George Boole (1815–1864), an English mathematician
Attempt to express in a symbolic notation human thought process, relationships, conditions
An investigation of the Laws of Thought–Defined Theorems
Using algebraic notation and operations was able to express logical thought
Boolean Algebra Laws similar in some ways to algebra with numbers
Extensively modified by subsequent mathematicians
Use of Boolean Logic in electronic circuits

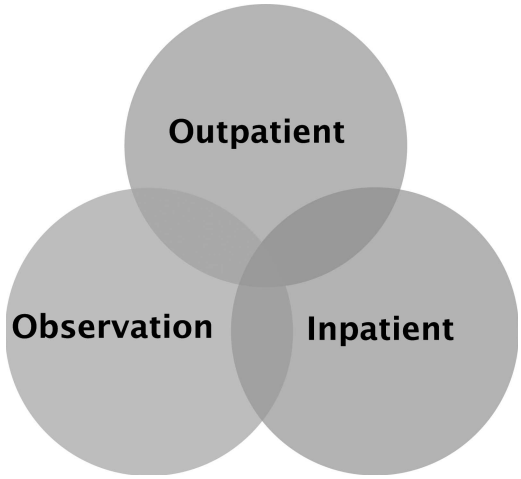

FIGURE 1
Venn diagram of hospital status.

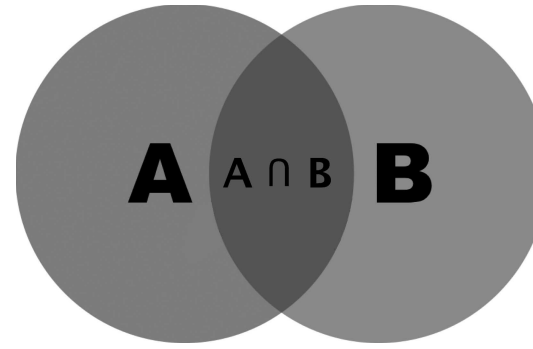

FIGURE 2
Intersection of screening sets. A is objective data, imaging, physiologic abnormalities, laboratory; and B is treatment medical, surgical.

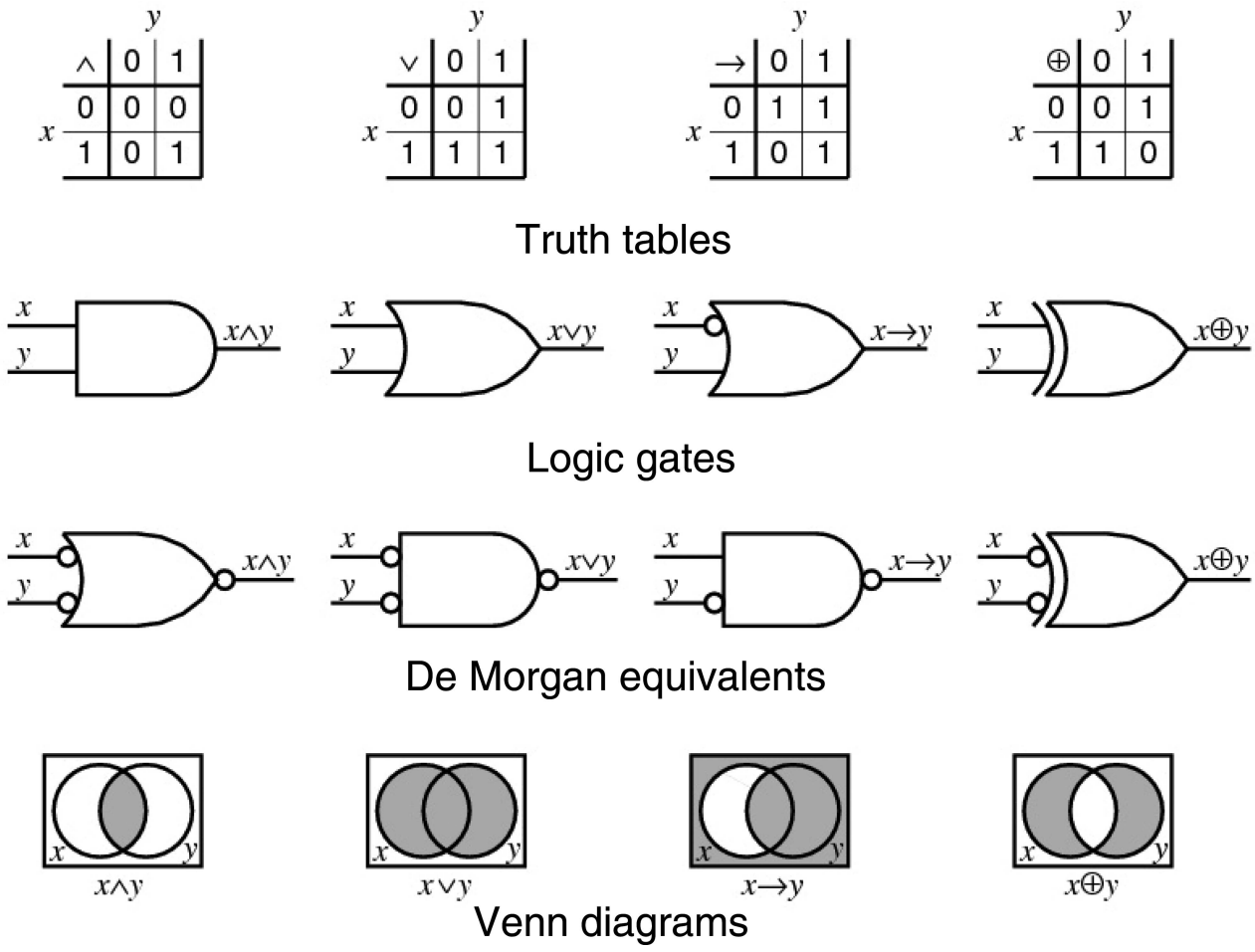

FIGURE 3
Various representations of Boolean operations. From "Four Figures for Boolean Algebra Article Boolean Algebra. Boolean Algebra (Logic)," by V. Pratt, 2007, February 4. In *Wikipedia, the free encyclopedia*. Retrieved February 12, 2012, from http://en.wikipedia.org/wiki/en:GNU_Free_Documentation_License

the set of all patients who have the characteristics of inpatients and *Y* and *Z* are patients who have the characteristics that satisfy the standard screening systems and secondary system, respectively. However, if sets *Y* and *Z* were combined as a union of sets, the OR function, then the union of the two sets would describe the majority of those that are considered inpatients. It could be stated that infrequently there could be patients who satisfy neither screening systems and would be designated as the set $X(1 - Y) + X(1 - Z)$. One advantage of graphically displaying these sets is to conceptualize that the goal is to have as many cases satisfy the standard screening systems and emphasize rigor in the proper interpretation of the documentation. What is not desired is to have large numbers of patients with medical problems that may be common but are not considered inpatients and the treatment of these conditions is not considered inpatient treatments. Conditions that are common and are clearly not designated as inpatient by screening systems are severely restricted not to being made inpatients.

Entropy to Describe Medical Information

An interesting historical confluence ties the concepts of Boolean Logic, Logic Gates, and the use of Information Theory in medical information and ultimately in status determination. Claude Shannon of the Massachusetts Institute of Technology was instrumental in all of these concepts (Brown, 2003). Common usage of entropy in science is known as a term of thermodynamics that systems tend to become more disordered (Shannon & Weaver, 1963). Entropy in information theory does not describe information but describes the degree of uncertainty and what is the amount of information that is required to resolve that uncertainty. A recent definition of entropy is a measure of the uncertainty of a random variable (Cover & Thomas, 2006). When a patient presents to an emergency department initially, he may have the potential of having any one of many medical problems. This potential group of illness may be described in probability theory as a random variable

TABLE 4
Status Determination as a Boolean Function

$Y + Z + X(Y' + Z') - X = 0$

If the Universal Set under discourse is all patients

Inpatient and Outpatient $- X + X'$

X are those having the characteristics of inpatients

Y are those inpatients who satisfy the criteria of the screening system

Z are those inpatients who satisfy the criteria of the secondary system

Y', Z' not having characteristics of Y or Z but are subsets of X or X'.

or a set of random variables within a range of events possible for that particular patient (Rozanov, 1969). Although there may be formal or informal assessment of probability of a certain event or outcome as part of medical evaluation, this is less likely to be stated explicitly until the assessment is complete. The theory of entropy used in information theory would state that the more uncertain the patient's problem is, the greater the amount of information that would be required to transmit the message (Pierce, 1980).

H(*X*) is the symbol for entropy and as shown in Figure 5, that entropy is the highest when the probability of the event occurring is equal chance or 0.5. As the probability either increases or decreases, the entropy moves toward 0. Entropy in information theory is interested in how much the message can be compressed and communicated with an acceptable amount of error, and there are mathematical models that define how much information in binary information is required as a measure of entropy (Pierce, 1980).

In a patient the information would come from the traditional forms of history, physical examination, laboratory, and imaging studies. Ideally, the medical assessment would interpret the available information

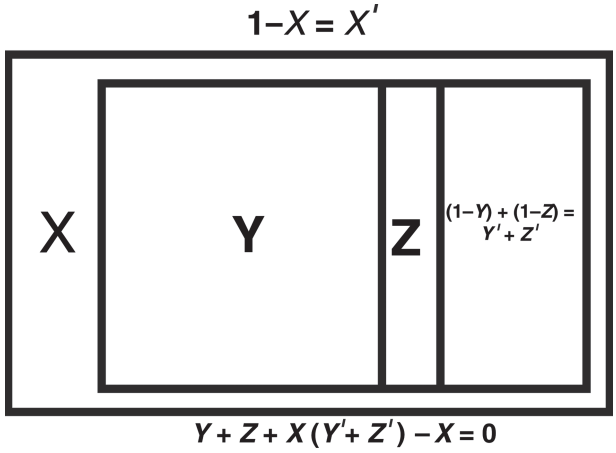

FIGURE 4
Status determination as a Boolean function.

Within this conceptual framework of decreasing uncertainty as information is acquired, the optimal time for status determination possibly should not be defined as absolute time but as a parameter of a minimum amount of information obtained.

and provide, when possible, a number of diagnoses with a statement of treatments and prognosis. This is contrasted with a less than optimal assessment that restates the information already known and details what further evaluation is to be done, which may be a less-efficient use of the information. When a patient presents to an emergency department, the number of possible outcomes is very large. As information is obtained in a successive manner over increasing time, the potential diagnoses and treatment options may become less uncertain.

For status determinations there are only two possible outcomes: inpatient or outpatient. These must be synthesized from many complex pieces of data. Once the information is obtained and organized sufficiently, then the methods of analysis with the screening systems are utilized as defined previously. Within this conceptual framework of decreasing uncertainty as information is acquired, the optimal time for status determination possibly should not be defined as absolute time but as a parameter of a minimum amount of information obtained.

It appears to follow that the goal of medical evaluation and treatment is to decrease uncertainty in

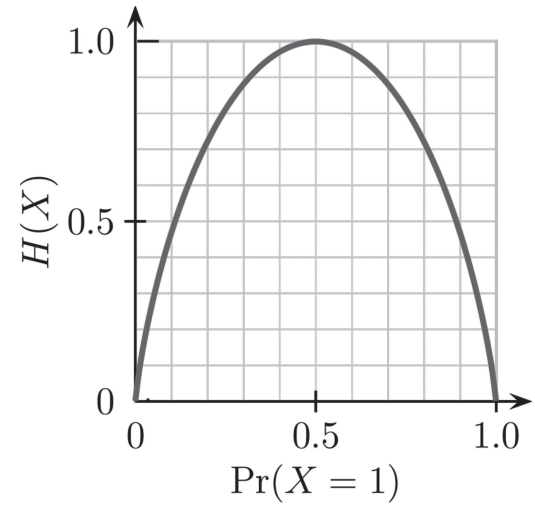

FIGURE 5
Entropy as a function of probability. From "Brona, 2012, August 29. In *Wikipedia, The Free Encyclopedia*. Retrieved August 30, 2012, from http://en.wikipedia.org/wiki/en:GNU_Free_Documentation_License.

terms of medical risk to the patient and resolve uncertainty with respect to what is the proper treatment of the patient. Time is an important component with respect to resolving uncertainty, and it seems reasonable that with additional time and information the entropy of the information would decrease. Decreasing entropy does not mean that the medical situation is less serious or less unstable only that it can now be defined with less information. An example of this would be an ST-segment elevation myocardial infarction, which by that term alone transmits a large piece of medical information of diagnosis, prognosis, and treatment that is specified not only qualitatively but also quantitatively with respect to time. Figure 6 suggests that medical information and the corresponding entropy vary over time but it is hypothesized that there is a decreasing trend overall. The question would be whether there is an optimal time when the medical information and the entropy are such that a reevaluation of the patient would change the medical utilization that was required.

Discussion

The association of logic with the medical diagnostic process is not new. A classic text of bedside diagnosis (DeGowin & DeGowin, 1976), which is well known to physicians of a senior vintage, begins the first chapter titled, "Logic and Diagnosis." The outline is successive acquisition of facts, evaluation of facts, listing of the hypothesis, and choosing between hypotheses. It is reasonable to consider that this outline of conceptual steps, in fact, uses Boolean and Set Theory concepts. In the section Evaluation of Facts, it encourages one to "conclude whether the items are *trivial* or *relevant*" to the identification of disease. The

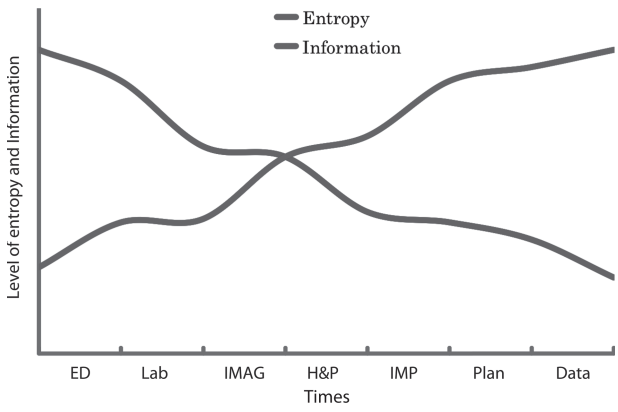

FIGURE 6
Entropy change with time and information. ED = emergency department; Lab, laboratory; IMAG, imaging studies; H&P, history and physical; IMP, impression; plan, plan of treatment; data, additional data.

The question would be whether there is an optimal time when the medical information and the entropy are such that a reevaluation of the patient would change the medical utilization that was required.

word trivial or relevant could correspond to designating the items as being considered as a binary variable. The diagnostic "clues" are matched with characteristics of known diseases, and the diseases are narrowed down to the most likely, which is the intersection of the sets of characteristics and diseases. Of course, this approach describes diagnosis; in the modern hospital environment the diagnosis may be more apparent because of the advancement of diagnostic studies but the correct setting for treatment and the threshold for that treatment continue to be difficult to define.

Utilization review has a primarily goal that is administrative in nature, that is, to place patients in the proper status and fulfill our obligation to provide assistance as to the optimal utilization of resources and patient care. It is stated at the outset that these issues are marked by potential conflict between patient care and placing barriers to that care (Trerise, Dodek, Leung, & Spinelli, 2001).

The methods contained in this article have been used to organize medical information in a consistent framework. An important task would be to clarify how these concepts can be used in diverse case management situations. One issue is that the correct hospital status category is not always intuitive to the practicing physician because of the external standards of screening systems and other criteria-based systems. A definitive decision by case management that cannot be clearly explained may be seen as arbitrary and lacking clinical acumen. The concepts of a priori and a posteriori define information in terms of an ideal model compared with the information that is specific to the patient under consideration. The principles of Boolean Logic and set theory are useful in making a definitive decision, evaluating characteristics of patients, and validating specific pieces of medical data. Information theory recognizes that information acquisition is dynamic over time as is the uncertainty which has been presented as medical entropy. An interesting question would be, what is the optimal time for making a status determination. This question encompasses the variables of time and information, as well as resolution or increase in uncertainty or entropy. Experience would suggest that the optimal time would be at the start of the admission when the attending physician documents the history, physical

examination, and assessment of available data and orders the treatment plan. In the case of an emergency department referral for admission, these data enhance the accuracy of the decision. An admission direct from the office or clinic may be lacking in adequate information to assess uncertainty and risk. In this circumstance, the status may be initially designated as an outpatient awaiting further information.

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