ORIGINAL RESEARCH

Primary Triage in a Mass-casualty Event Possesses a Risk of Increasing Informational Confusion: A Simulation Study Using Shannon's Entropy

Yasuhiko Ajimi, MD, DMSc;[1] Masaru Sasaki, MD;[2] Yasuyuki Uchida, MD;[1] Ichiro Kaneko, MD, PhD;[1] Shinya Nakahara, MD, PhD;[1] Tetsuya Sakamoto, MD, PhD[1]

1. Department of Emergency Medicine, School of Medicine, Teikyo University, Tokyo, Japan
2. Tokyo Metropolitan Hiroo Hospital, Tokyo, Japan

Correspondence:
Yasuhiko Ajimi, MD, DMSc
Trauma & Resuscitation Center
Department of Emergency Medicine
School of Medicine, Teikyo University
2-11-1 Kaga, Itabashi-ku, Tokyo 173-8606, Japan,
E-mail: relievedtemple436@gmail.com

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Abstract

Introduction: Primary triage in a mass-casualty event setting using low-visibility tags may lead to informational confusion and difficulty in judging triage attribution of patients. In this simulation study, informational confusion during primary triage was investigated using a method described in a prior study that applied Shannon's Information Theory to triage.

Hypothesis: Primary triage using a low-visibility tag leads to a risk of informational confusion in prioritizing care, owing to the intermingling of pre- and post-triage patients. It is possible that Shannon's entropy evaluates the degree of informational confusion quantitatively and improves primary triage.

Methods: The Simple Triage and Rapid Treatment (START) triage method was employed. In Setting 1, entropy of a triage area with 32 patients was calculated for the following situations: Case 1 – all 32 patients in the triage area at commencement of triage; Case 2 – 16 randomly imported patients to join 16 post-triage patients; Case 3 – eight patients imported randomly and another eight grouped separately; Case 4 – 16 patients grouped separately; Case 5 – random placement of all 32 post-triage patients; Case 6 – isolation of eight patients of minor priority level; Case 7 – division of all patients into two groups of 16; and Case 8 – separation of all patients into four categories of eight each. In Setting 2, entropies in the triage area with 32 patients were calculated continuously with each increase of four post-triage patients in Systems A and B (System A – triage conducted in random manner; and System B – triage arranged into four categories).

Results: In Setting 1, entropies in Cases 1-8 were 2.00, 3.00, 2.69, 2.00, 2.00, 1.19, 1.00, and 0.00 bits/symbol, respectively. Entropy increased with random triage. In Setting 2, entropies of System A maintained values the same as, or higher than, those before initiation of triage: 2.00 bits/symbol throughout the triage. The graphic waveform showed a concave shape and took 3.00 bits/symbol as maximal value when the probability of each category was 1/8, whereas the values in System B showed a linear decrease from 2.00 to 0.00 bits/symbol.

Conclusion: Informational confusion in a primary triage area measured using Shannon's entropy revealed that random triage using a low-visibility tag might increase the degree of confusion. Methods for reducing entropy, such as enhancement of triage colors, may contribute to minimizing informational confusion.

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Introduction

Triage in a disaster setting is defined as the process of prioritizing patients for care after a mass-casualty event, treating as many as possible with the limited resources available.[1] Therefore, patients with high priority must be transported immediately and assigned to appropriate therapies. However, most triage tags used worldwide, including those used in Japan, do not have high visibility. This often makes it difficult to distinguish, from a distance, pre- and post-triage patients, or their priority levels, especially in darkness or inclement wheather.[2] In these situations, determining priorities for patients through primary triage may lead to confounding of essential information regarding patients' prioritization for care at the triage scene. In this simulation study, given the crucial factors in primary triage of reliability and validity,[3,4] informational confusion during primary triage in the setting of a mass-casualty event was investigated by applying Shannon's Information Theory[5] to a disaster triage setting, using a method described in a prior study.[6]

In Shannon's Information Theory, entropy is defined as the average amount of information from all symbols (ie, elements generated from an information source) arising from the information source.[5] An amount of information is measured according to the probability of an event. The less likely an event is, the more information it provides when it occurs. It is calculated using the logarithm of the inverse of the probability arising from symbols drawn from the information source, measured in bits, the basic unit of information in computing and digital communication.[7] Entropy represents the uncertainty of probability arising from symbols in the source. The larger the entropy of an information source, the more difficult it is to predict symbols arising from the source.

Here, a simulation study was performed using a simplified primary triage model in a mass-casualty event setting, and degrees of informational confusion at the triage scene were compared among several triage settings using Shannon's entropy as a measure of uncertainty of triage category information.[5]

Hypothesis

The primary triage area with a specific number of patients represents a source of information about priority levels for patient care. Determining the priorities by primary triage using a low-visibility tag leads to a risk of confusion regarding essential priority-level information in a triage area, owing to the intermingling of pre- and post-triage patients. Shannon's entropy is an indicator of uncertainty of information arising from an information source. If this indicator can be adapted for use at the primary triage scene, it will be possible to quantify the degree of informational confusion in the triage area as the uncertainty of priority-level information, and to improve triage tags or other methods related to primary triage.

Methods

Setting 1

Eight different situations within a triage area during a mass-casualty event were designated Cases 1 through 8. These eight cases were designed to investigate the effect of degree of separation on entropy of the triage scene with half-triaged (Cases 2-4) and fully triaged (Cases 5-8) persons. Entropy was calculated according to each situation.

The total number of patients was 32. The severities of patients' injuries were unknown before triage. Triage was performed in a completely random manner. The case settings were as follows (Figure 1):

1. Case 1: All 32 patents were salvaged to the triage area.
2. Case 2: An additional 16 patients were imported randomly to the triage area just after the first 16 were triaged.
3. Case 3: An additional 16 patients were imported just after the first 16 were triaged. Eight of the additional 16 were moved randomly to Side A of the triage area and the other eight were placed on Side B of the area.
4. Case 4: An additional 16 patients were imported to Side B of the triage area, completely separated from Side A where triage of the first 16 patients was completed.

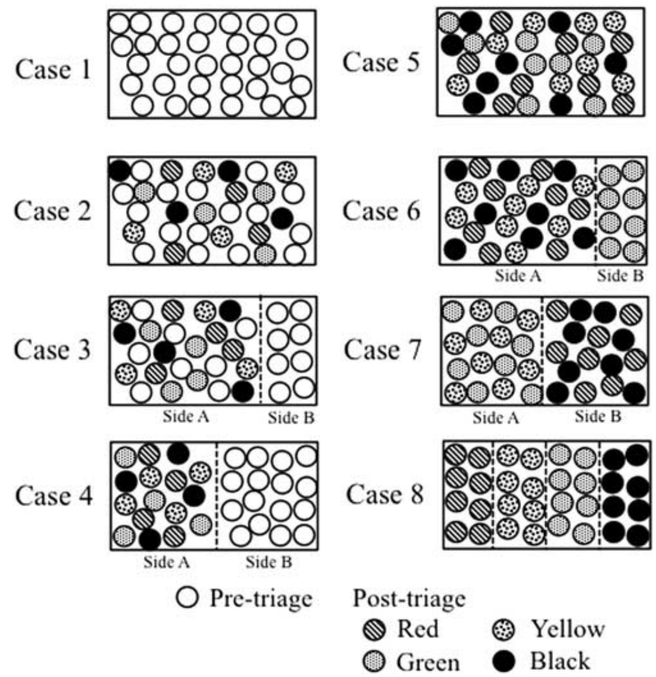

Figure 1. Each of the Eight Cases in Setting 1 Consists of 32 Patients.
Case 1: pre-triage patients only. Each of Cases 2-4 consists of 16 pre-triage patients and 16 post-triage patients. Each of Cases 5-8 consists of post-triage patients only. Patients in these cases were divided differently according to post-triage levels. A pre-triage patient means a patient for whom a priority level is not determined by triage. A post-triage patient means a patient for whom a priority level is determined and has been given a triage tag.

5. Case 5: Triage of all 32 patients was completed and placed randomly.
6. Case 6: Triage of all 32 patients was completed. Eight patients with green tags (minor priority) were brought together on Side B, completely separated from Side A where post-triage of 24 patients with the three other levels of priority were placed randomly.
7. Case 7: Triage of all 32 patients was completed. Sixteen patients with delayed or minor priority were placed randomly on Side A, completely separated from Side B where 16 patients with immediate or expectant priority were placed randomly.
8. Case 8: Triage of all 32 patients was completed and prioritized with respect to four categories.

Medical preparedness of the triage system consisted of the following: a triage officer (one person); and triage criteria. The triage criteria were that of Simple Triage and Rapid Treatment (START) triage[2] consisting of four categories: immediate (red), delayed (yellow), minor (green), and expectant (black). For this study, the first step in the algorithm (removal of green patients simultaneously from the triage area by loud vocal command) was skipped because removal of green patients at the first step simultaneously reduces the number of categories to three from the four that were necessary to calculate entropy in more detail. In the following report, a pre-triage patient means a patient for whom a priority level was not determined

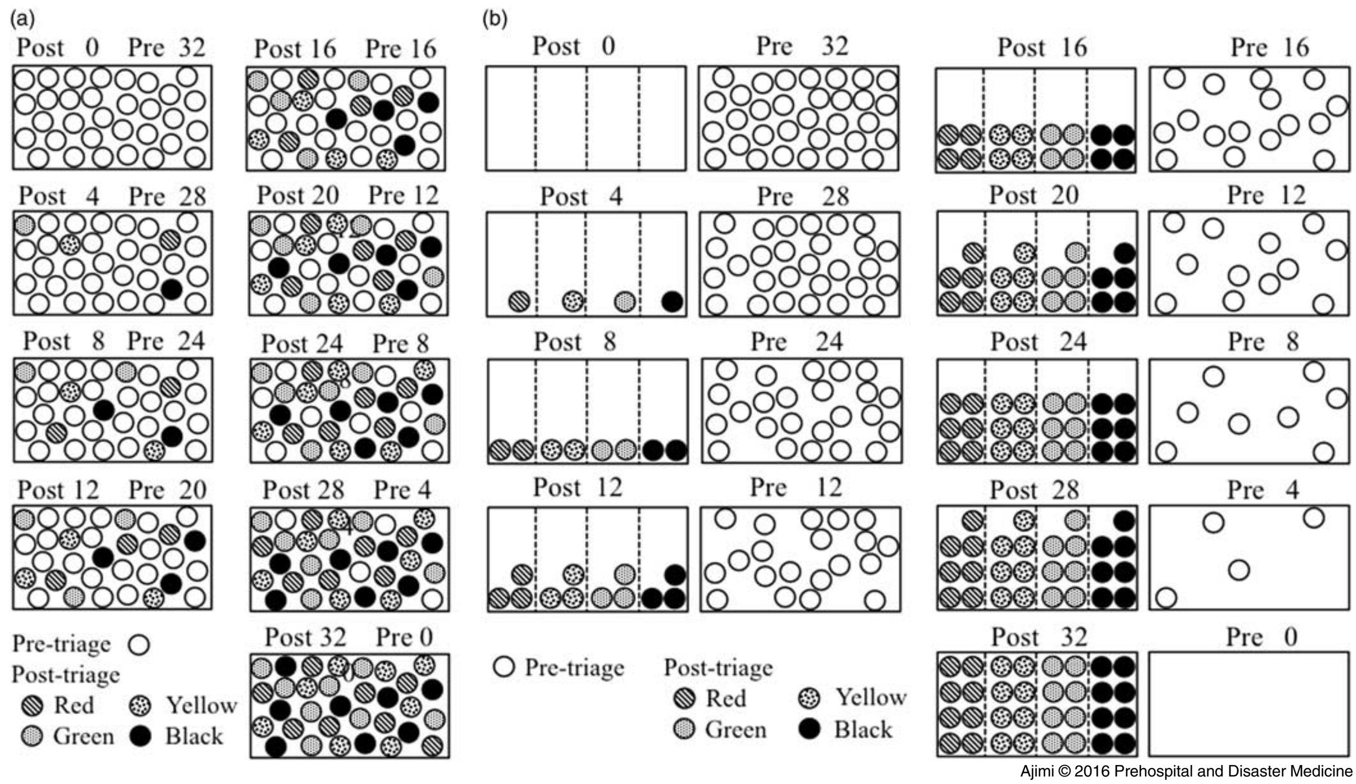

Figure 2. (a) Triage Process of System A in Setting 2. **(b)** Triage Process of System B in Setting 2.
A pre-triage patient means a patient for whom a priority level is not determined by triage. A post-triage patient means a patient for whom a priority level is determined and has been given a triage tag.

by triage. A post-triage patient means a patient for whom a priority level was determined and was given a triage tag.

Setting 2

The total number of patients in the mass-casualty event was 32, the same as in Setting 1. Injury severity of patients was unknown. Medical preparedness of the triage system was also the same as in Setting 1. In this setting, all 32 patients were salvaged and imported to the triage area at the outset of triage:

1. System A: Triage was performed in a completely random manner (Figure 2A).
2. System B: Triage was performed in a completely random manner. The post-triage patients were arranged with respect to four categories delineated near the triage area whenever triage was completed (Figure 2B).

Entropy values were calculated continuously with respect to each increase of four post-triage patients in these two systems until all 32 patients were converted to post-triage (Figure 2A and Figure 2B).

Calculation of Entropy

Each element generated from an information source is called a symbol.[8,9] An expected value for the amount of information from the source is called entropy (H) and is calculated by the following formula:[8,9]

$$H = -\sum_{i=1}^{n} Pi \log_2 Pi \qquad (1)$$

where Pi is arising probability of each symbol from the source; $\log_2 Pi$ is the amount of information of each symbol in the source, whose unit of measure is bits; and n is the number of symbols contained in the source. H is entropy, which also indicates uncertainty of a symbol arising from the source, and has bits per symbol (bits/symbol) as its unit of measure.

H takes a maximal value in the case that each symbol arises in the same probability:[7]

$$H = -\log_2 1/\text{n}. \qquad (2)$$

Entropies of the mass-casualty event scene were calculated in all cases by applying information regarding patients' categories of the START method to formulas (1) and (2).

If an information source consists of two parts that have different entropies, H_A and H_B, and the portions of their arising probabilities are P_A and P_B ($P_A + P_B = 1.0$), the total entropy is calculated by the following formula:[9]

$$H = P_A H_A + P_B H_B. \qquad (3)$$

Results

Setting 1

The entropy was calculated in each case. The results are shown in Table 1.

Case 1—Before categorizing all 32 patients in the triage area into four priority levels according to START triage criteria, given that the injury severity of the patients was unknown, the probability of each category was 1/4. According to formula (2), H in Case 1 was $H = -\log_2(1/4) = 2.00$ bits/symbol.

	No. of Post-Triage Patients		No. of Pre-Triage Patients		
Case No.	Random	Separate	Random	Separate	Entropy (bits/symbol)
1	0	0	32	0	2.00
2	16	0	16	0	3.00
3	16	0	8	8	2.69
4	16	0	0	16	2.00
5	32	0	0	0	2.00
6	24	8	0	0	1.19
7	16[a]	16[a]	0	0	1.00
8	0	32	0	0	0.00

Table 1. Entropy of Each Case in Setting 1

[a] The terms "random or separate" used in Case 7 have different meanings from those used in the other cases. A pre-triage patient means a patient for whom a priority level is not determined by triage. A post-triage patient means a patient for whom a priority level is determined and has been given a triage tag.

Case 2—An additional 16 patients were imported randomly to the triage area just after triage of the first 16 patients was complete. The probability of each category of post-triage patients with low-visibility tags in Case 2 was $16/32 \times 1/4 = 1/8$, and the probability of each category of the additional 16 pre-triage patients was $1/2 \times 1/4 = 1/8$. According to formula (1), H in Case 2 was $H = (1/8) \times \log_2(8/1) \times 4 + (1/8) \times \log_2(8/1) \times 4 = 3/2 + 3/2 = 3.00$ bits/symbol. Because the probability of pre- and post-triage was the same (1/8), H in Case 2 also was calculated according to formula (2), $H = \log_2(8/1) = 3.00$ bits/symbol.

Case 3—Eight of the additional 16 patients were imported randomly to Side A of the triage area (Figure 1) and the other eight were placed in Side B, completely separated from Side A. The probability of each category of post-triage patients in Side A was $1/4 \times 2/3 = 1/6$. The probability of each category of pre-triage patients in Side A was $1/4 \times 1/3 = 1/12$. According to formula (1), H_A as H in Side A was $H_A = (1/6) \times \log_2(6/1) \times 4 + (1/12) \times \log_2(12/1) \times 4 = 2.92$ bits/symbol. The probability of each of the four categories in Side B was 1/4. According to formula (2), H_B as H in Side B was $H_B = -\log_2(1/4) = 2.00$ bits/symbol. P_A and P_B as the probabilities of Side A and Side B were $24/32 = 3/4$ and $8/32 = 1/4$. According to formula (3), the total entropy of Case 3 was $H = P_AH_A + P_BH_B = 3/4 \times 2.92 + 1/4 \times 2.00 = 2.69$ bits/symbol.

Case 4—All of the additional 16 patients were imported to Side B of the triage area, completely separated from Side A, where the first 16 patients were triaged. The probability of post-triage patients of each category in Side A was 1/4. According to formula (2), H_A as H in Side A was $H_A = -\log_2(1/4) = 2.00$ bits/symbol. The probability of pre-triage patients of each category in Side B was 1/4. According to formula (2), H_B as H in Side B was 2.00 bits/symbol. P_A and P_B as the probabilities of Side A and Side B were $16/32 = 1/2$ and $16/32 = 1/2$. According to formula (3), the total entropy of Case 4 was $H = P_AH_A + P_BH_B = 1/2 \times 2.00 + 1/2 \times 2.00 = 2.00$ bits/symbol.

Case 5—All 32 patients were triaged. The probability of post-triage patients of each category in the triage area was 1/4. According to formula (2), entropy in Case 5 was $H = -\log_2(1/4) = 2.00$ bits/symbol.

Case 6—Patients with a green tag indicating minor priority were collected separately from those with other priority levels. The probability of each category level of post-triage patients in Side A was 1/3. According to formula (2), H_A as H in Side A was $H_A = -\log_2(1/3) = 1.58$ bits/symbol. The probability of minor priority in Side B was 1. According to formula (2), H_B as H in Side B was $H_B = -\log_2(1) = 0.00$ bits/symbol. P_A and P_B as the probabilities of Side A and Side B were $24/32 = 3/4$ and $8/32 = 1/4$. According to formula (3), the total entropy of Case 6 was $H = P_AH_A + P_BH_B = 3/4 \times 1.58 + 1/4 \times 0 = 1.19$ bits/symbol.

Case 7—The probability of the yellow or green category in Side A was 1/2. The probability of the immediate or expectant priority in Side B was also 1/2. According to formula (2), H_A and H_B were $-\log 2_2 (1/2) = 1.00$. P_A and P_B as the probabilities of Side A and Side B were 1/2. According to formula (3), the total entropy of Case 7 was $H = P_AH_A + P_BH_B = 1/2 \times 1.00 + 1/2 \times 1.00 = 1.00$ bits/symbol.

Case 8—All post-triage patients were separated completely. The probability of each category was 1. According to formula (2), H in each category was $H = -\log_2(1) = 0.00$ bits/symbol. According to formula (3), the total entropy of Case 8 was $H = 1 \times 0.00 \times 4 = 0.00$ bits/symbol.

Setting 2

The entropies were calculated continuously with respect to each increase of four post-triage patients in Systems A and B until all 32 patients were converted to post-triage. The results are shown in Table 2 and Figure 3:

1) All 32 patients were not triaged.

No. of Pre-Triage Patients	No. of Post-Triage Patients	P(pre)	P(post)	P(pre-e)	P(post-e)	H of Style A	H of Style B
32	0	1.000	0.000	0.250	0.000	2.00	2.00
28	4	0.875	0.125	0.219	0.031	2.54	1.75
24	8	0.750	0.250	0.188	0.063	2.81	1.50
20	12	0.625	0.375	0.156	0.094	2.95	1.25
16	16	0.500	0.500	0.125	0.125	3.00	1.00
12	20	0.375	0.625	0.094	0.156	2.95	0.75
8	24	0.250	0.750	0.063	0.188	2.81	0.50
4	28	0.125	0.875	0.031	0.219	2.54	0.25
0	32	0.000	1.000	0.000	0.250	2.00	0.00

Table 2. Change in Entropies of Settings 1 and 2 Accompanying Progress in Triage
Note: *P*(pre), probability of pre-triage patients; *P*(post), probability of post-triage patients; *P*(pre-e), probability of pre-triage patients with each triage category; *P*(post-e), probability of post-triage patients with each triage category. A pre-triage patient means a patient for whom a priority level is not determined by triage. A post-triage patient means a patient for whom a priority level is determined and has been given a triage tag.

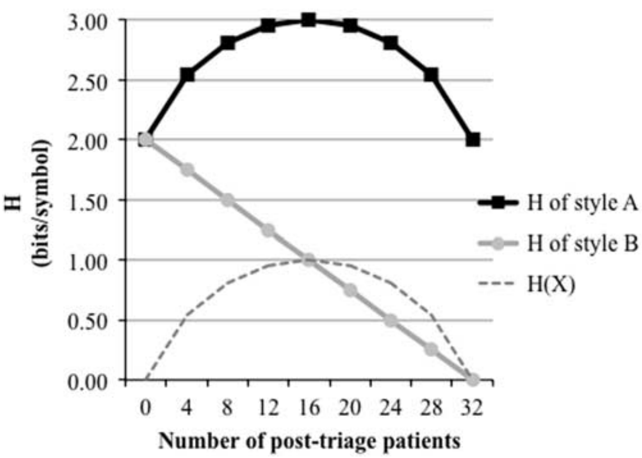

Figure 3. Graphic Comparison of Change in Entropies of Systems A and B (shown in Table 2). The dotted line indicates waveform of $H(X)$ explained in the Discussion. A pre-triage patient means a patient for whom a priority level is not determined by triage. A post-triage patient means a patient for whom a priority level is determined and has been given a triage tag.

a) System A: Random triage.
As the severity of the patients' injuries were unknown, the probability of each category was 1/4. According to formula (2), entropy in System A was $H = \log_2 4 = 2.00$ bits/symbol.
b) System B: Transport just after random triage.
Before triage, entropy in System B was the same as in System A, $H = \log_2 4 = 2.00$ bits/symbol.

2) Four patients were triaged. Twenty-eight were not yet triaged.

a) System A: Random triage.
The probability of post-triage patients was $4/32 \times 1/4 = 1/32$, and the probability of each category of pre-triage patients was $28/32 \times 1/4 = 7/32$. According to formula (1), entropy of System A was $H = (1/32) \times \log_2(32/1) \times 4 + (7/32)\log_2(32/7) \times 4 = 2.544$ bits/symbol.
b) System B: Transport just after random triage.
The probability of each category of pre-triage patients was 1/4. According to formula (2), H_{pre} as H of pre-triaged patients was $H_{pre} = -\log_2 (1/4) = 2.00$ bits/symbol. The probability of post-triage patients in the area of transported patients was $4/4 = 1$. According to formula (2), H_{post} as H of the transported patients was $H_{post} = (1/1) \times \log_2(1/1) = 0.00$ bits/symbol. P_{pre} and P_{post} as the probability of the pre-triage and post-triage areas were $28/32 = 7/8$ and $4/32 = 1/8$. According to formula (3), the entropy of System B was $H = P_{pre}H_{pre} + P_{post}H_{post} = 7/8 \times 2.00 + 1/8 \times 0 = 1.75$ bits/symbol.

3) Eight patients were triaged. Twenty-four were not yet triaged.

a) System A: Random triage.
The probability of each category of post-triage patients was $8/32 \times 1/4 = 1/16$, and the probability of each category of pre-triage patients was $24/32 \times 1/4 = 3/16$. According to formula (1), entropy was $H = (1/16) \times \log_2(16/1) \times 4 + (3/16) \times \log_2(16/3) \times 4 = 2.811$ bits/symbol.
b) System B: Transport just after random triage.
The probability of each category of pre-triage patients in the triage area was 1/4. According to formula (2), H_{pre} as H of pre-triaged patients was $H_{pre} = -\log_2(1/4) = 2.00$ bits/symbol. The probability of post-triage patients in the area of transported patients was $4/4 = 1$. According to formula (2), H_{post} as H of the transported patients was $H_{post} = (1/1) \times \log_2(1/1) = 0.00$ bits/symbol. P_{pre} and P_{post} as the probability of the pre-triage area and post-triage area were $24/32 = 3/4$ and $8/32 = 1/4$. According to formula (3), the entropy of system B was $H = 3/4 \times 2.00 + 1/4 \times 0 = 1.50$ bits/symbol.

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Figure 4a-d. Low Visibility of a Triage Tag Placed on a Patient in a Triage Area.

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Figure 5. Idea to Increase the Visibility of Priority Levels. Post-triage patients are covered with fluorescent colored caps.

Table 2 shows entropies calculated in each situation where the numbers of post-triage patients were 12, 16, 20, 24, 28, and 32.

Figure 2 shows a comparison of changes in entropy between Systems A and B. Entropies of System A maintained values the same as, or higher than, pre-initiation values throughout the triage. The waveform showed a concave shape and took the maximal value when the probability of each category was 1/8.

Discussion

Triage in a disaster is defined as the process of prioritizing patients for care after a mass-casualty event, treating as many as possible with the limited resources available.[1] As the priority is related directly to patients' prognosis, reliability and validity mainly have been emphasized and discussed with regard to disaster triage.[3,4] However, it is not enough merely to prioritize patients for care after triage; it also is essential to share such important information among the staff at the mass-casualty event scene to help treat the patients as soon as possible. If a primary triage is performed randomly in a mass-casualty event setting using a low-visibility tag, the risk of informational confusion at the scene is increased because of the existing mixture of pre- and post-triage patients. Figure 4 focuses on a person in a triage area who cannot be assessed as pre- or post-triage. Even if post triage, his priority of care mostly is not visible. Approaching from the directions shown by arrows in Figure 4a-c, it is difficult to identify his tag color.

The tag and its priority can be revealed as yellow (delayed) only after taking a position just beside him as shown in Figure 4d. A primary triage using such low visibility can cause informational confusion in the triage area.

In this study, the degree of informational confusion regarding priority of care in a primary triage scene was measured as Shannon's entropy following the protocol of a previous study,[4] and the entropy was compared in different situations.

In Setting 1, the entropies of informational confusion in Cases 1 and 8 were calculated as positive and negative baselines. In Cases 2-4, one-half of all patients were imported to the triage area just after the other half of the patients were triaged. Although the number of pre- and post-triage patients was 16 in these three cases, the values of the entropy decreased according to the degree of separation of pre- and post-triage patients: completely random, half-separated, and completely separated. Furthermore, the entropy in Case 1 (before triage), Case 4 (half complete), and Case 5 (all complete) had the same value.

In Setting 2, entropies were calculated successively and the changes were compared between Systems A and B on the presumption that sequential transport of post-triage patients was equivalent to isolating new patients from post-triage patients in terms of reducing informational confusion. Surprisingly, the values of entropy in System A remained higher than that of the baseline. The graph of System A (Figure 3) showed a parallel shift of the following function[9] toward the y axis by +2 bits:

$$X = 1 \text{ with probability } P,\ X = 0 \text{ with probability } 1-P$$
$$H(X) = -P\log_2 P - (1-P)\log_2(1-P),\ H(X) = 1 \text{ bit when } P = 1/2,$$

whereas the values in System B showed a linear decrease.

The results of Settings 1 and 2 showed that entropy may represent a quantitative indicator of informational confusion in a primary triage area.

Finally, this study suggests that a random primary triage using a low-visibility tag might increase the risk of informational confusion as regards patients' priority for care. This phenomenon was considered to occur because of the additional work necessary during primary triage to distinguish whether patients are pre- or post-triage and perception of their priority levels from a distance. To reduce this risk, several methods are considered useful: (1) triage from end to end; (2) enhance post-triage patients with high-visibility tags; (3) separate newly salvaged patients from post-triage patients; (4) decrease the number of categories (eg, removal of the ambulatory patients at initiation of triage employed by methods such as START); and (5) transport post-triage patients sequentially. One possible means to augment Method (2) is to use four kinds of fluorescent colored caps, as shown in Figure 5. Method (5) may be difficult to implement at a disaster scene where there are insufficient personnel to transport the patients. However, if the balance of medical supply and demand recovers, a rapid triage with sequential transport of post-triage patients, regardless of priority levels, would be an important option.

According to Major Incident Medical Management and Support (MIMMS),[10] the aims of triage are not only to deliver the right patient to the right place at the right time so that they receive the optimum treatment, but also to "do the most for the most," accepting that valuable medical resources should not be diverted toward treating an irrecoverable condition. If primary triage in a mass-casualty event includes the intention to reduce the extent of informational confusion in a triage area, the results of this study can be applied to this description: sequential transport suits triage in terms of the former precept, and separation of pre-triage patients or enhancement of visibility for post-triage patients suits the latter.

Although the results of this study seem adaptable to common practice for an actual mass-casualty event triage, they need to be validated through primary triage training.

Limitations

This report presents a simple theoretical model according to the protocol of the prior article.[5] Calculation of entropy is based on the same probability among the four categories of START triage. An assumed tag employed in this simulation study was difficult to distinguish, and from a distance, the priority was difficult to judge because of its low visibility. Further confirmation is needed regarding to what extent entropy is related to the degree of informational confusion at a primary triage scene.

Conclusions

Degrees of informational confusion in a primary triage area in different situations were evaluated quantitatively using Shannon's entropy. A random triage using a low-visibility tag may increase the degree of confusion. Methods for reducing entropy, such as separation of newly salvaged patients, enhancement of triage colors, or sequential transport of post-triage patients, may contribute to minimization of informational confusion in prioritizing the care of patients in a primary triage area.

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