Supplementary Material

Appendix A: details about the five outcome measures.

All data can be downloaded from https://data.cms.gov/provider-data/topics/hospitals/overall-hospital-quality-star-rating. In general, each outcome is defined by the following four steps:

1. Extract measures from the databases related to the outcome.
2. Rank all hospitals by each measure (in descending order) and obtain the percentile as the scores.
3. Calculate the average score.
4. Obtain the percentile of the average score as the score for the outcome.

In step 1, the measures corresponding to each of the five outcomes are listed below:

Mortality

1. Death rate for heart attack patients
2. Death rate for coronary artery bypass graft (CABG) surgery patients
3. Death rate for chronic obstructive pulmonary disease (COPD) patients
4. Death rate for heart failure patients, (5) Death rate for pneumonia patients
5. Death rate for stroke patients,
6. Deaths among patients with serious treatable complications after surgery from the database

Complication and Infections (extracted from csv files: Complications_and_Deaths-Hospital.csv, Healthcare_Associated_Infections-Hospital.csv)

1. Central line-associated bloodstream infection rate (CLABSI),
2. Catheter-associated urinary tract infection rate (CAUTI),
3. Surgical site infections from colon surgery (SSI: Colon),
4. Surgical site infections from abdominal hysterectomy (SSI: Hysterectomy)
5. Methicillin-resistant Staphylococcus aureus (MRSA) Blood Laboratory-identified Events (Bloodstream infections)
6. Clostridium difficile (C. diff) Laboratory-identified Events (Intestinal infections)
7. Serious complications from the database

Readmission (extracted from csv file: Unplanned_Hospital_Visits-Hospital.csv)

1. Rate of readmission after discharge from hospital (hospital-wide)

Patient Experience (extracted from csv file: OQR_OAS_CAHPS_BY_HOSPITAL.csv)

1. Patients who reported that their nurses communicated well
2. Patients who reported that their doctors communicated well
3. Patients who reported that they received help as soon as they wanted

4. Patients who reported that staff explained about medicines before giving it to them
5. Patients who reported that their room and bathroom were clean/ Patients who reported that the area around their room was quiet at night,
6. Patients who reported that they were given information about what to do during their recovery at home
7. Patients who understood their care when they left the hospital
8. Patients who gave their hospital a rating on a scale from 0 (lowest) to 10 (highest)/ Patients who would recommend the hospital to their friends and family from the database

The score of Timely and Effective Care (extracted from csv file: Timely_and_Effective_Care-Hospital.csv)

1. Percentage of healthcare workers given influenza vaccination
2. Percentage of patients who left the emergency department before being seen
3. Percentage of patients who came to the emergency department with stroke symptoms who received brain scan results within 45 minutes of arrival
4. Percentage of patients receiving appropriate recommendation for follow-up screening colonoscopy
5. Percentage of patients with history of polyps receiving follow-up colonoscopy in the appropriate timeframe
6. Percentage of mothers whose deliveries were scheduled too early (1-2 weeks early), when a scheduled delivery was not medically necessary
7. Percentage of patients who received appropriate care for severe sepsis and septic shock
8. Percentage of outpatients with chest pain or possible heart attack who got drugs to break up blood clots within 30 minutes of arrival
9. Percentage of patients receiving appropriate radiation therapy for cancer that has spread to the bone
10. Average (median) time patients spent in the emergency department, after the doctor decided to admit them as an inpatient before leaving the emergency department for their inpatient room
11. Average (median) number of minutes before outpatients with chest pain or possible heart attack who needed specialized care were transferred to another hospital
12. Average (median) time patients spent in the emergency department before leaving from the visit
13. Percentage of outpatients with low-back pain who had an MRI without trying recommended treatments first, such as physical therapy
14. Percentage of outpatient CT scans of the abdomen that were “combination” (double) scans
15. Percentage of outpatients who got cardiac imaging stress tests before low-risk outpatient surgery from the database.

Appendix B:

Proposition: The area of origami plot is: proportional to the average of the arm lengths and invariant to reordering of the axes. The area of the radar plot is not uniquely defined up to a reordering of axes.

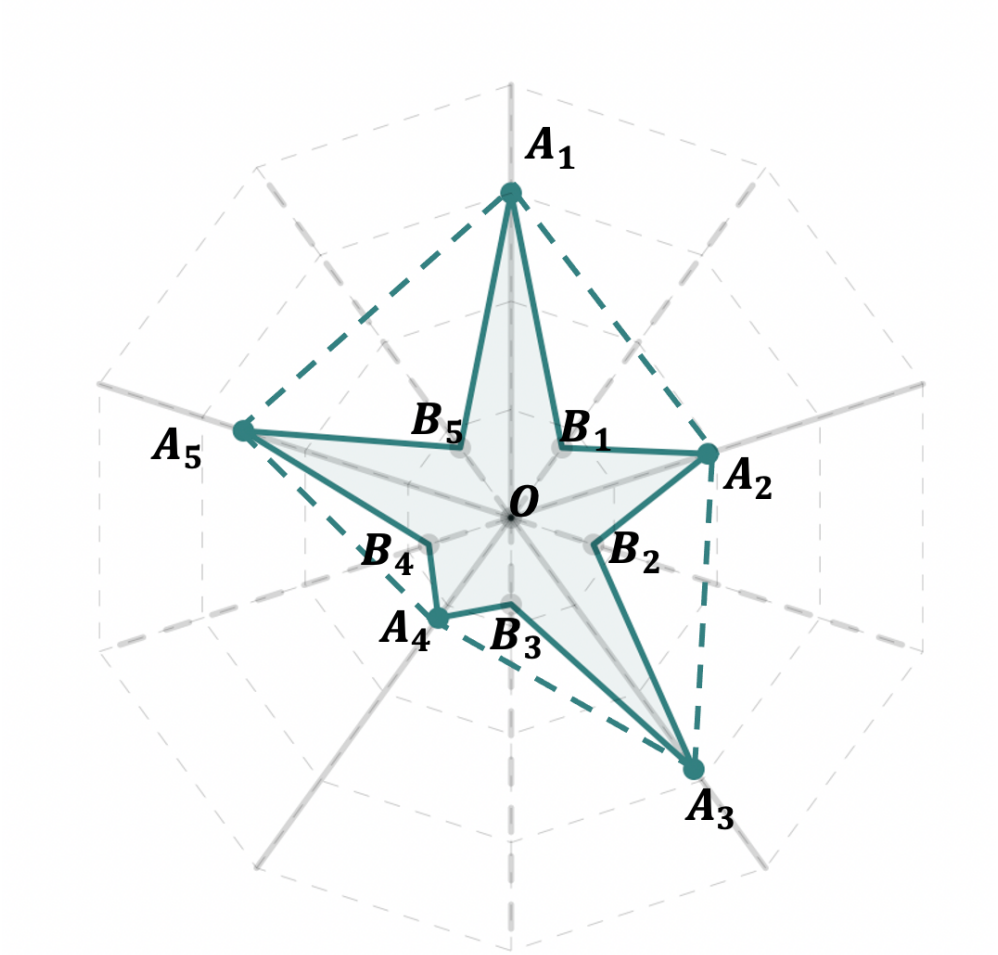

Figure S1: 5-pointed origami plot with A_i and auxiliary points B_i. The green region is the area of the origami plot. The region enclosed by the dashed line is the area of the corresponding radar plot.

Proof:

Suppose we have an origami plot with K outcomes. Starting from the top main axis and moving clockwise, label each point on each main axis as $A_1, A_2, \dots, A_K$, and each point on each auxiliary axis as $B_1, B_2, \dots, B_K$. The center point is labelled as O (Figure S1). Let S be the area of the green

shaded region corresponding to the origami plot and let R be the area of the region enclosed by the dashed line corresponding to the radar plot.

By construction, each segment OB_k has the same length, say d. Let the length of OA_k be h_k. The angles $\angle A_k O B_k$ and $\angle A_k O B_{k-1}$ are each $\frac{\pi}{K}$ radians and the angles $\angle A_k O A_{k+1}$ are $\frac{2\pi}{K}$ radians where $A_{K+1} \equiv A_1$ and $B_{K+1} \equiv B_1$. Denote the area of triangle $\Delta A_k O B_k$ as s_k, the area of triangle $\Delta A_k O A_{k+1}$ as r_k, and note that the areas of $\Delta A_k O B_k$ and $\Delta A_k O B_{k-1}$ are the same.

Then using the geometric fact that the area of any triangle is equal to one-half the product of two adjacent sides and the sine of the angle subtended by them,
we have

$$s_k = \frac{1}{2}\sin \angle A_k O B_k \, h_k d = \frac{1}{2}\sin \angle A_k O B_{k-1} \, h_k d = \frac{1}{2}\sin\left(\frac{\pi}{K}\right) h_k d$$

and

$$r_k = \frac{1}{2}\sin \angle A_k O A_{k+1} \, h_k h_{k+1} = \frac{1}{2}\sin\left(\frac{2\pi}{K}\right) h_k h_{k+1}$$

The total area S of the origami plot is

$$S = 2\sum_{k=1}^{K} s_k = \sum_{k=1}^{K} \sin\left(\frac{\pi}{K}\right) h_k d = \sin\left(\frac{\pi}{K}\right) d \sum_{k=1}^{K} h_k = \sin\left(\frac{\pi}{K}\right) K \bar{h} d$$

where $\bar{h}$ is the average of the arm lengths h_k. The area is proportional to $\bar{h}$ and is invariant to labelling of the axes because it is a function only of the sum of the arm lengths.

The total area R of the origami plot

$$R = \sum_{k=1}^{K} r_k = \sum_{k=1}^{K} \sin\left(\frac{2\pi}{K}\right) h_k h_{k+1} = \sin\left(\frac{2\pi}{K}\right) \sum_{k=1}^{K} h_k h_{k+1}$$

which depends on the ordering of the axes since in general $\sum_{k=1}^{K} h_k h_{k+1}$ is not the same after permutation of the axes.

Appendix C: on the choices of the distance between points on the auxiliary axes and the origin.

Here we use an example (shown in Figure S2) to illustrate the pros and cons of selecting a short distance versus a long distance. Basically, with a short distance (closer to the origin than all the points on the main axes), all the arms on the main axes are pointing outward, which highlights the main axes. With a longer distance, some of the angles on the main axes may be pointing inward while some are pointing outward, which creates some difficulty to distinguish the main axes from the auxiliary axes. The limitation of choosing a short distance is that it will lead to thin arms when the shortest distance formed by the scores is small, making it hard to visualize and compare the area of the shaded region. Regardless of the choices, it doesn't change the fact that the area is invariant to the order of axes.

In some special settings, it may provide additional information. For example, in the hospital profiling example, we choose the auxiliary distance to be 0.5, which indicates the median across all hospitals. By checking if the angle is pointing inward or outward, we can easily tell if a score is above or below the median, as illustrated by right panel of Figure R2.

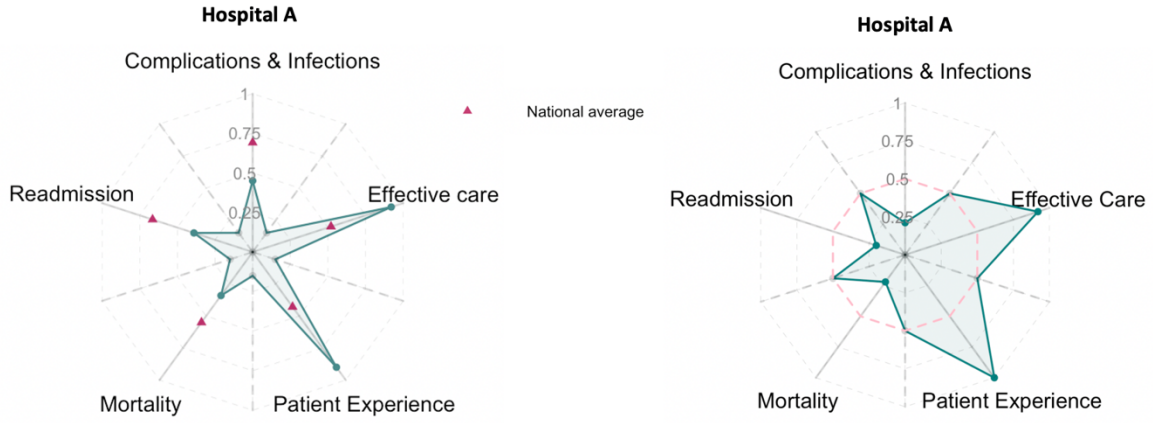

Figure S2: Comparison between two origami plots. Left: points on the auxiliary axes are closer to the origin than any points on the main axes. Right: points on the auxiliary axes are in the middle of the auxiliary axes.