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Short Communication

A useful data presentation tool: Ternary plots in forensic medicine

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A B S T R A C T

Ternary plots are triangle shaped diagrams which display the proportions of three given categories in an information dense format. This short communication aims at demonstrating ternary plots as a method of data presentation in forensic medicine. In addition, a practical example is given and discussed. They are generally underutilized in medicine and forensic medicine in particular. This method paper describes how to read and design ternary plots. Template files are provided. Example diagrams for "manner of death in custody" are demonstrated and discussed.

1. Introduction

Data visualization is an important aspect of research. There are many different graphs and plots, which are suitable to different kinds of data. According to Tufte [1], referring to *quantitative data*, data visualization should aim for a maximum proportion of "ink representing data", minimize elements which do not convey data, ensure graphical integrity, and strive for high-quality design.

In forensic medicine groups and populations are frequently described and compared, often in the form of *ternary data*, where variables are limited to only three categories which add up to 100%. Examples include:

- Nominal data without quantitative value:
  - manner of death in a country or department (natural, non-natural, undetermined),
  - manner of death amongst non-natural death (suicide, homicide, accident).
- Ordinal data, which is often *quantitative data* which has been sorted ("binned") into categories:
  - weight (underweight, normal weight, overweight),
  - age (children, adults, elderly),
  - velocity (low, medium, high).

Unlike binary data (Yes vs. No, Male vs. Female, ...), it is often difficult to display ternary data across different groups in a condensed and accessible manner, which allows both a quick overview and in-depth analysis.

Ternary plots (TP) (not to be confused with *ternary phase diagrams*) are specialized plots for such scenarios. TP come in the shape of equilateral triangles, which use a barycentric coordinate system, where the location of a point is specified by value triples. When two values are known, the third follows automatically, for example with categories A, B and C, when there is 60% A and 30% B, then 10% must be C. Multiple groups may share the same plot. To make TP more readable, areas of interest may be marked by lines or colors ("zoning"). Soil texture diagrams by the United States Department of Agriculture (USDA) [2,3] for example use such markings. In medicine the diagram for the solubilization of bile salts from 1966 [4] (see Fig. 1) is a well known TP example.

See "Method" for details how to read and create TP.

2. Method

Reading TP (refer to Fig. 2): Each side of the equilateral triangle serves as a scale from 0% to 100%. Corners alternate between 0% and 100% for the adjacent sides. The scales are continued as parallel lines inside the triangle to form a grid. The orientation of tick marks helps with the allocation of scales to grid lines. Axis labels often run in a different orientation from the grid, which is counter-intuitive for readers who are used to X/Y coordinates.

To find the proportion triple of a TP marker, one must simply follow the grid lines to the corresponding scales on the sides. Knowing two percentages automatically gives the third. TP readability and intuitive interpretation may be increased significantly by color zoning for dominance — where a certain property represents >50%. This leaves an area of indifference in the plot center, where neither property dominates beyond 50%. Additional color zoning of the corners for emphasized

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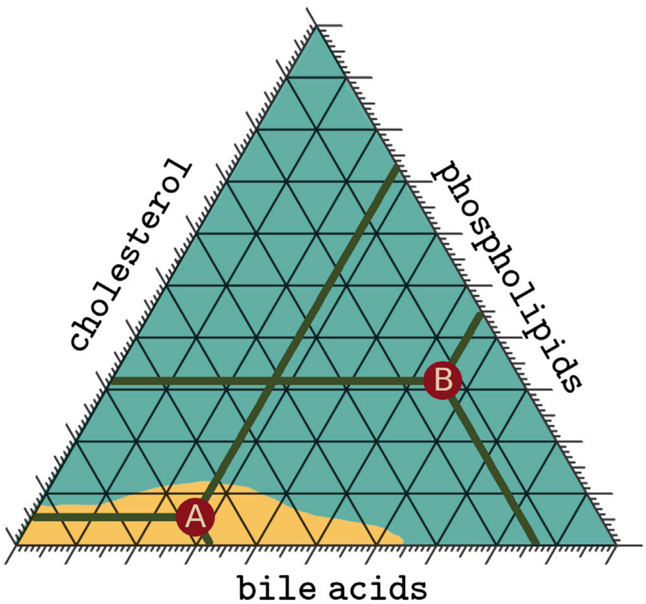

Fig. 1. Diagram for the solubilization of bile salts, simplified. "A" and its proportions for cholesterol, phospholipids, and bile acids is located in the "soluable" zone, while "B" is located in the "precipitation" zone.

dominance >80% introduces a visual clue of direction, where "the far side", away from the colored corner is considered logically as low proportion. By using color zoning, markers can be interpreted more intuitively in terms of "predominantly A, while leaning towards B" or "absence of C, equally divided between A and B". Often, values may only be approximated in TP, using the grid system with a precision of a few percentage points. When such approximation is acceptable, axis labeling may be omitted altogether (for example Fig. 3).

If one category is strongly underrepresented across several data sets, markers will fall on the outer edges of the TP. Thus, TP is not recommended for data visualization for such data sets.

Creating TP: After data selection and preparation, markers may be drawn into a template manually. Additional information may be added via the markers' colors, sizes and shapes, as well as by different zoning colors, labels, and other means. The graphics in this publication, including Fig. 3, were created using the graphic processing software Gimp [5]. More conveniently, a template (provided in the electronic supplementary materials) may be used as slide backgrounds in MS PowerPoint and customizable shapes added.

3. Results

For demonstration in this brief communication, we present results of a *rudementary literature review on death in custody* and its visualization using TP. A thorough review and discussion of the referenced publications is *not* intended.

13 publications were reviewed for "manner of death in custody":

- Australia (2000) [6],
- Canada (2002) [7],
- USA: Nebraska (1999 and 2012) [8,9], Texas (2015) [10], and Maryland (2007) [11],
- China (2019) [12],
- India (2016) [13],
- Malaysia (2018) [14],
- Korea (2012) [15],
- Germany (2009) [16],
- Romania (2012) [17].

Please consult the visualizations and retrace the conclusions in Fig. 3 (TP) as well as Fig. 4 (conventional bar charts displaying the same data for comparison):

"Undetermined" manner of death is rare for death in custody cases and TP markers generally collect close to "the far side of dark blue/undetermined" in the ternary plot. Notable exceptions are South Africa (roughly 25% undetermined) and Maryland, USA (roughly 20% undetermined). Between those two, South African manner of death leans towards non-natural deaths while Maryland, USA, is split almost equally between the remaining natural and non-natural deaths. In the conventional bar chart, it is difficult to compare non-neighboring bars such as Germany and Nebraska.

The other groups show only low proportions of "undetermined" death. The split between natural and non-natural deaths is inconsistent. There are both high proportions of natural death (Romania) and high proportions of non-natural death with "clumping" for Australia, India, and Germany around the 80/20 non-natural to natural death split. This grouping occurs naturally in TP as it would in scatter plots and other grid coordinates. In the bar chart, due to its tabular nature, such sorting cannot occur.

Looking at the lower TP of Fig. 3 concerning "suicide, homicide, accident" amongst non-natural deaths, the publication from Germany strikes as an outlier for its high proportion of accidents. A possible explanation is the cohort's rather short-term police custody soon after arrest with plenty of accidental overdosing from drugs and alcohol in contrast to long term incarcerations in prisons and jails. South Africa's limited access to toxicology resources at the time of publication may explain both its high proportion of "undetermined deaths" in all cases and the apparent absence of "accidents" in the bottom TP since lethal overdosing remained "undetermined" and was therefore not classified as accidental.

Korea strikes as another outlier since the non-natural cases in the publication included exclusively suicides.

For the Malaysia cohort, data suggests a highly violent environment in prisons, with both non-natural death in general as well as homicide proportions being high. However, case numbers were low for this study (8/6).

Exceptions like Germany, Korea and Malaysia are likewise easily detected in the bar chars. It is however much more difficult to detect subtle details such as the dominance of one property over the other (for example 40% versus 45%).

For Nebraska, USA, two publications from 1999 and 2012 were available. With a low proportion of "undetermined" deaths, the values for natural vs. non-natural death showed little change in between the two publications. Within non-natural death, the proportions shifted away from suicide-dominated towards a "balanced indifference" of one third each for suicides, accidents and homicides.

This change in Nebraska is well visible in both Figures. In the bar chart however it is much less obvious that Nebraska has shifted from a distribution close to that of China to one close to that of Australia.

4. Discussion

Not all research can (or should) be accommodated as three variables and displayed using TP. For example, in most scenarios it will not make sense to divide gender into "male/female / non-binary", when for the different cohorts the "non-binary" portion is extremely small. Likewise, artificially breaking down killing methods into "blunt force, sharp force, and strangulation" would probably not help with comparing groups or drawing conclusions either. So caution and common sense should be exercised.

However, as demonstrated using a rudementary literature review on "death in custody", TP can be employed effectively and sensibly in the setting of forensic medical research. TP also enable the reader to explore data sets and theorize about possible implications. This can be enhanced further by coloring and labeling. In our example it was

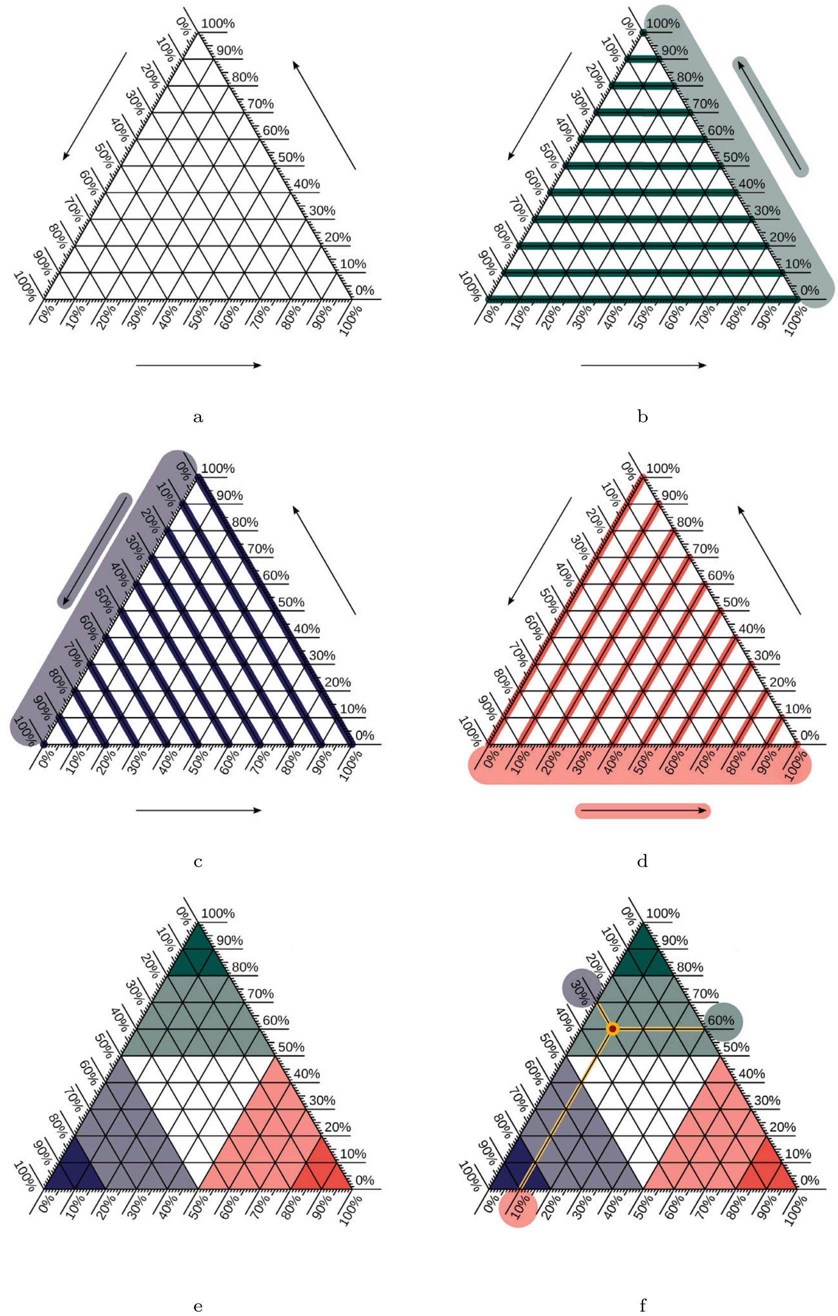

Fig. 2. (a) Empty ternary plot. (b–d) Scales and coordinate lines highlighted. (e) Color zoning for >50% dominance (light) and >80% emphasized dominance (dark). (f) Example of marker at 30% blue, 60% green, 10% red.

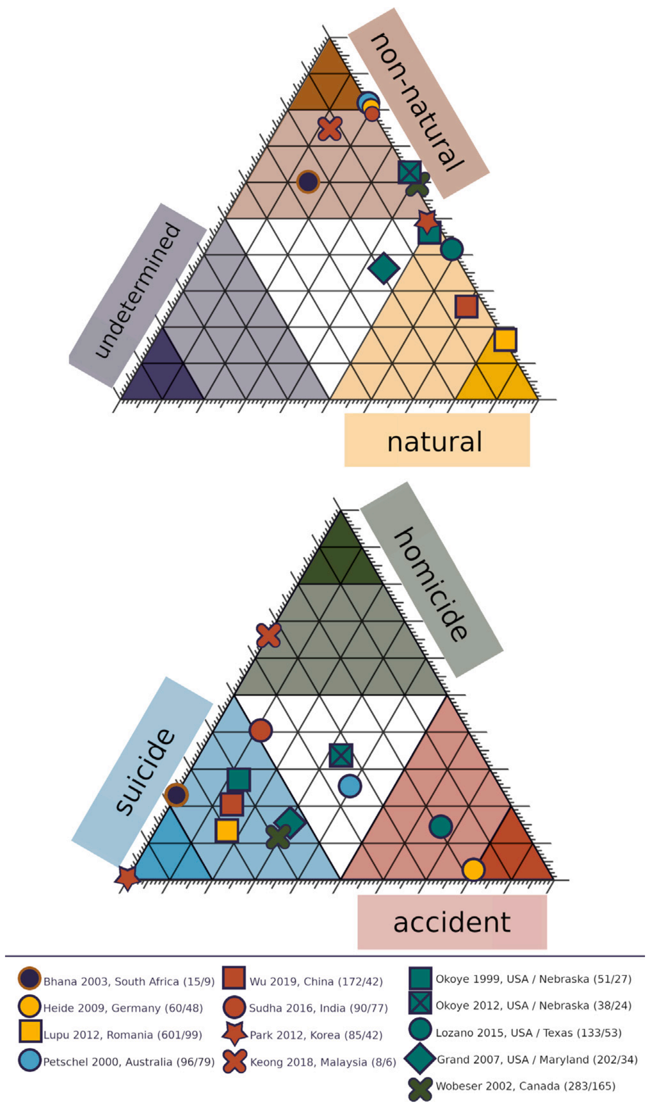

Fig. 3. Ternary plots for “manner of death”. Top: natural vs. non-natural vs. undetermined. Bottom: suicide vs. homicide vs. accident within non-natural deaths from top. Note different shade of green for Canada in the North America group. The relevant case count is presented in the legend (parentheses, left). Below, the proportions of suicide, accident and homicide are shown *within the sub-group of non-natural deaths* (case count in parentheses, right), including killings by police.

easy to identify that in the majority of publications, suicide was the dominating manner of death amongst “non-natural” deaths in custody. South Africa and Malaysia can be identified easily as the highest proportions of “undetermined” deaths. It is easy to put publication results into context when all are displayed in one TP.

In forensic medicine, there are many possible use cases. Examples include

- cohorts of people (women, children, men),
- age groups (pre-, post-, and working age),
- nutritional state (underweight, normal weight, overweight),
- manner of death (natural, non-natural, undetermined/homicide, suicide, accident),
- location (inner city, motorway, highway).

We would like to encourage the reader to consider ternary plots for data visualization in forensic medicine.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

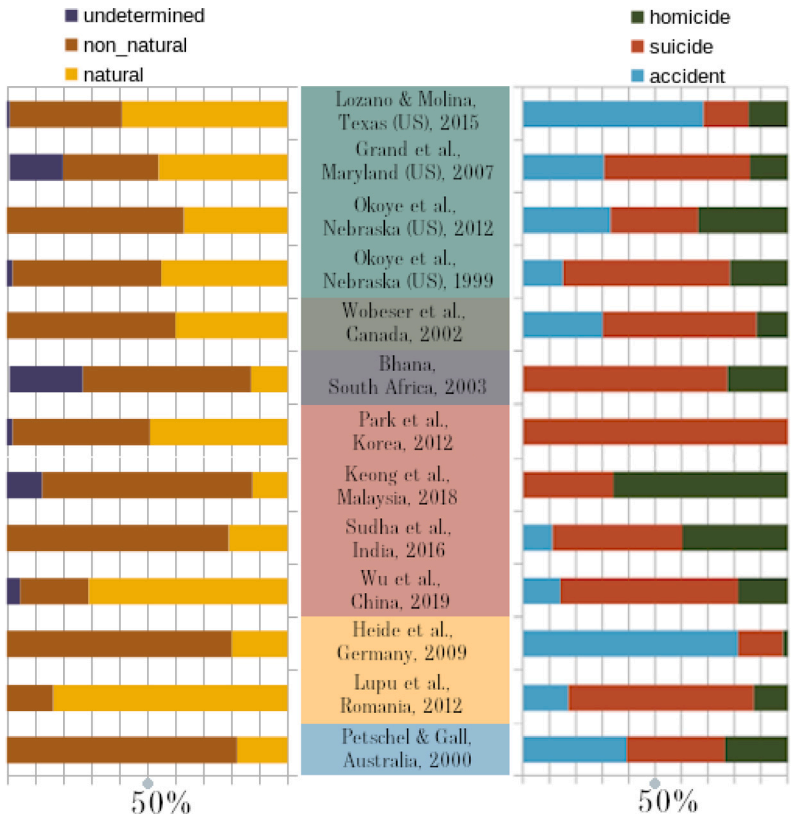

Fig. 4. Conventional data display using stacked bar charts. Left: natural vs. non-natural vs. undetermined. Right: homicide vs. suicide vs. accident within the non-natural cases. Color coding for continents as in Fig. 3.

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