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# Predicting Expected Organ Donor Numbers in Australian Hospitals Outside of the Donate-Life Network Using the ANZICS Adult Patient Database

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**Background.** The majority of organ donations in Australia occur in the DonateLife Network of hospitals, but limited monitoring at other sites may allow donation opportunities to be missed. Our aim was to estimate expected donor numbers using routinely collected data from the Australian and New Zealand Intensive Care Society Adult Patient Database and determine whether unrecognized potential donors might exist in non-DonateLife hospitals. **Methods.** All deaths at 150 Australian intensive care units (ICUs) contributing to the Australian and New Zealand Intensive Care Society Adult Patient Database were analyzed between January 2010 and December 2015. Donor numbers were extracted from the Australian and New Zealand Organ Donor registry. A univariate linear regression model was developed to estimate expected donor numbers in DonateLife hospitals, then applied to non-DonateLife hospitals. **Results.** Of 33 614 deaths at 71 DonateLife hospitals, 6835 (20%) met criteria as "ICU deaths potentially suitable to be donors," and 1992 (6%) were actual donors. There was a consistent relationship between these groups ($R^2 = 0.626$, $P < 0.001$) allowing the development of a prediction model which adequately estimated expected donors. Of 8077 deaths in 79 non-DonateLife ICUs, 452 (6%) met criteria as potentially suitable donors. Applying the prediction model developed in DonateLife hospitals, the estimated expected donors in non-DonateLife hospitals was 130. However, there were only 75 actual donors. **Conclusions.** It is possible to estimate the expected number of Australian organ donors using routinely collected registry data. These findings suggest that there may be a small but significant pool of underutilized potential donors in non-DonateLife hospitals. This may provide an opportunity to increase donation rates.

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Organ transplantation is a rare but potentially lifesaving treatment for thousands of Australians who have end stage organ failure. A major reason it remains a rare event is that only about 1% of Australians who die in hospital do so in circumstances in which organ donation is feasible.[1] This is also a reason why it is vital that all efforts be made to maximize identification of patients who may be suitable to become donors.

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In the previous decade, data showed Australia's donation rate per million population (dpmp) to be relatively lower than other developed countries with comparable health systems and epidemiology of patients.[2] In response, the Australian national organ donation reform was launched in 2008.[3] One of the key aspects of this reform was the establishment of the Australian DonateLife Network of hospitals. These are mostly tertiary and metropolitan hospitals, all with an intensive care unit (ICU), which were identified as having the greatest capacity for potential organ donors. Increased resources have been channeled into these centers including funding, onsite donation specialist staff, educational programs, and data collection for all potential and actual donors in the form of the DonateLife audit.

Since the introduction of the DonateLife Network in 2009, deceased organ donor numbers in Australia have steadily increased by 82%, or from 11.4 to 20.8 dpmp up until 2016.[4,5] The majority of these organ donations occurred at DonateLife Network hospitals with data from recent DonateLife audits indicating that few potential donors are now missed at these sites.[3,5] In non-DonateLife hospitals, where donor numbers have been much lower, the maximum potential for organ donation, and thus whether there exists an untapped pool of possible donors, remains unknown.

The majority of Australian ICUs contribute to the Australian and New Zealand Intensive Care Society (ANZICS) Adult Patient Database (APD)[6] including those within and those outside of the DonateLife Network. Given almost all donations occur in an ICU setting, we reasoned that this routinely collected data could be used to investigate the relationship between the number of organ donors at each hospital and the number and characteristics of patients who died within the hospital's ICU. If such a relationship existed, then this could be used to estimate the expected number of donors in hospitals outside the DonateLife Network.

More specifically, our hypothesis was that the number of adult organ donors was related to and could be predicted from the number of deaths in each ICU that met specific suitability criteria on admission. Our aim was to develop and validate a prediction tool to estimate organ donor numbers within DonateLife hospitals and then to apply this prediction tool to the remaining non-DonateLife hospitals to determine if there is untapped potential for donation at these hospitals.

## MATERIALS AND METHODS

### Setting and Source of Data

We conducted a retrospective analysis using data submitted to the Australian and New Zealand Organ Donor (ANZOD) registry and to the ANZICS APD, 1 of 4 clinical quality registries run by the ANZICS Centre for Outcome and Resource Evaluation, between January 2010 and December 2015.

The ANZOD registry has recorded and reported on organ donation statistics on a monthly and annual basis since its inception in 1989. This includes a detailed breakdown of donors by pathway, that is, donation after circulatory or brain death, region, and organ type. These data are used for monitoring and benchmarking performance on a national and international level.

The ANZICS APD collects deidentified information on patients admitted to adult ICUs in Australia, including survival outcome, admission diagnosis and chronic health status, together with physiological and biochemical variables from the first 24 hours of admission, required for the Acute Physiology and Chronic Health Evaluation[7,8] and Australian and New Zealand Risk of Death severity of illness scoring systems.[9] No specific information related to brain death status or the outcome of organ donation is recorded.

### Development of Criteria to Identify ICU Deaths Potentially Suitable to be Organ Donors Within the ANZICS APD

Criteria for potential suitability for organ donation were developed using a stepwise process, initially using local and international guidelines,[1,10,11] and then published scientific literature relating to organ suitability and factors likely to result in organ donation.[12-15] In the absence of consistent and definitive definitions, multiple versions of these criteria were developed, applied to the ANZICS APD, and then tested in an iterative process to determine which had the strongest correlation with donor numbers for each ICU.

General medical suitability criteria included: death in ICU, mechanically ventilated, and absence of an admission diagnosis or chronic history related to cancer or human immunodeficiency virus. Causes of death recognized in published literature[13,14,16-19] as compatible with likely progression to donation were identified using the relevant Acute Physiology and Chronic Health Evaluation III admission diagnosis codes, including cardiac arrest, neurological and trauma related diagnoses (**Tables S1 and S2, SDC**, http://links.lww.com/TP/B527). Organ-specific criteria were developed, based on the Transplant Society of Australia and New Zealand organ donation guidelines[1] and international guidelines[11] using information from the first 24 hours of ICU admission. This included lowest admission creatinine, highest $PaO_2/FiO_2$ ratio and lowest bilirubin, combined with a variety of age thresholds, and an absence of acute or chronic history of specific organ related disease. Multiple combinations of the above criteria were applied to the ANZICS APD. Each combination was tested for correlation with the actual number of organ donors (**Table S3, SDC**, http://links.lww.com/TP/B527). The number of patient deaths who met these criteria combinations within each contributing Australian ICU every quarter over the study period was extracted.

### Development of a Predictive Model to Estimate Donor Numbers

The number of organ donors, after both brain death and donation after circulatory death (DCD), at every hospital for each equivalent period was obtained from the ANZOD Registry. The combination of general medical suitability, organ suitability, and diagnostic criteria which had the highest correlation with quarterly organ donor numbers within DonateLife Network hospitals was identified using techniques described below. Patients aged between 18 and 75 years who died within the ICU and met this final set of criteria were considered "ICU deaths potentially suitable to be donors."

Univariable and mixed effects multivariable linear regression techniques were used to assess the relationship between actual donor numbers and the numbers of "ICU deaths potentially suitable to be donors" and to derive models to predict the number of donors within the DonateLife Network hospitals. The unit of analysis was the number of

donors within each hospital every 3 months. To avoid overfitting of the predictive model within DonateLife hospitals, the data set was randomly split into two third for development and one third for internal validation. All models assessed are described in the on-line supplemental digital content. Model performance was assessed by the $R^2$ value and Akaike and Bayesian Information Criteria, with the final and most parsimonious model chosen to balance simplicity, clinical applicability, and performance.

Estimations of expected numbers of donors were then generated for ICUs that were not part of the DonateLife Network and compared to actual donor numbers at these hospitals, using the process summarized in **Figure S1, SDC** (http://links.lww.com/TP/B527). Characteristics of patients within DonateLife Network ICUs and at non-DonateLife ICUs were also compared and were presented as number and proportion of each respective group, with chi square test for pair-wise comparisons. For all comparisons of actual and predicted donor numbers, the denominator was the total number of ICU deaths.

All hospital identifiers were removed from final data sets used for analysis. For reporting of results, the 4 smallest states and territories of Australia were combined and reported as a single region. Results were reported in accordance with strengthening the reporting of observational studies in epidemiology methodology[20] All data were analyzed using Stata version 14, Statacorp, College Station, Texas 77845, with construction of tables and graphs in Microsoft Excel. The study was approved by the Alfred Hospital human research ethics committee, Melbourne, Australia, with a waiver of informed consent. (study number 27/16).

## RESULTS

During the study period, 150 Australian hospitals contributed data from their ICUs to the ANZICS APD, including 71 of the 74 DonateLife Network hospitals. Of these, 60 had complete data for the whole of the 6 years of the study. Of the 79 non-DonateLife hospitals that contributed data to the ANZICS APD, 53 provided complete data for the study period.

There were 2374 actual organ donors throughout Australia listed in the ANZOD registry during this period. Of the 2274 donations that occurred in the DonateLife hospital ICUs, 1992 took place during periods when the ICU submitted data to the ANZICS APD. Of the remaining 100 donations in the non-DonateLife sites, 75 matched to periods where data from that ICU were available from the ANZICS APD.

Table 1 shows the criteria used to define "ICU deaths potentially suitable to be donors." Other potential combinations of criteria, which were rejected due to weaker associations with overall donor numbers, are presented in **Table S3, SDC** (http://links.lww.com/TP/B527). The relationship between the number of "ICU deaths potentially suitable to be donors" and actual donor numbers were well approximated by univariable linear regression using a fixed intercept ($R^2$ = 0.584 in derivation data set of 1055 quarters of site level data, $R^2$ = 0.626 in validation data set of 549 quarters of site level data, $P < 0.001$). The expected number of donors at each site could thus be simply estimated by multiplying the number of "ICU deaths potentially suitable to be donors" by 0.2889 (the β coefficient from the univariable linear regression). Other potential combinations of criteria to define an "ICU death potentially suitable to be a donor," and more complex predictive models involving multivariable linear regression, adjusting for hospital type, changes over time, and treating site as a random effect showed little or no improvement in performance over a univariable regression model and were therefore rejected in favor of the simpler model above. **Table S4, SDC,** (http://links.lww.com/TP/B527) details all regression models assessed with model 6 being the final model chosen). Figure 1 shows a scatter plot of the total number of "ICU deaths potentially suitable to be donors" against the actual number of donors at each site over the whole study period.

Table 2 shows the characteristics and comparisons between the different hospital types. DonateLife hospitals were predominantly large tertiary hospital ICUs, whereas the non-DonateLife hospitals were mainly private hospitals where deaths were more commonly elderly patients and those with comorbidities. There were 33 614 deaths within the 71 DonateLife hospital ICUs, of which 6835 (20%) met diagnostic, age and physiological criteria as "ICU deaths potentially suitable to be donors."

Overall expected and actual numbers of donors at DonateLife Network hospitals within each of the 4 regions of Australia and in each year of the study in both the derivation and validation data sets are shown in Table 3. In the derivation data set, the proportion of deaths at DonateLife Network hospital ICUs that became actual donors was similar to predicted (5.9% [1300/21 927] vs 5.9% [1298/21 927], $P$ = 0.97). In the validation data set, the proportion of deaths that were actual donors was also similar to predicted (5.9% (692/11 687] vs 5.8% [677/11 687], $P$ = 0.68).

There were 8077 deaths in the 79 non-DonateLife ICUs, of which 452 (6%) met criteria as "ICU deaths potentially suitable to be donors." Thus, a smaller absolute number and

**TABLE 1.**

**Factors used to define "ICU deaths potentially suitable to be donors"**

| General | Diagnosis | Organ specific |
|---|---|---|
| Age <75 y | Intracranial hemorrhage | Absence of chronic organ dysfunction |
| Death in ICU | Subarachnoid hemorrhage | |
| Absence of absolute contraindications: | Stroke Traumatic brain injury | Indices of organ function: $PaO_2/FiO_2$ ratio >250 |
| Active malignancy | Other neurological diagnoses | Bilirubin <65 μmol/L |
| HIV/AIDS Prion disease | Postcardiac arrest—anoxic brain injury | Creatinine <100 μmol/L |

See **Tables S1, S2, S3, and S4** (SDC, http://links.lww.com/TP/B527) for more detailed information.
HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome.

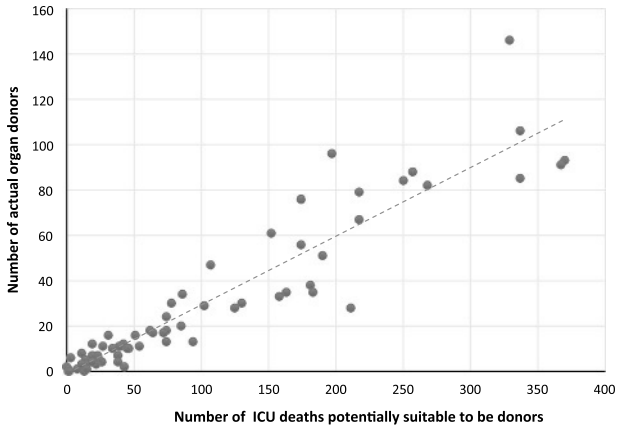


**FIGURE 1.** The number of "ICU deaths potentially suitable to be donors" versus the actual number of donors at each DonateLife site.

proportion of the 8077 deaths in non-DonateLife hospital ICUs were predicted to become donors than at DonateLife Network hospitals (1.6% [131/8077] vs 5.7% [1931/33614], $P < 0.001$). In the non-DonateLife hospitals, the absolute number and proportion of deaths who became donors was significantly less than expected (0.9% [75/8077] vs 1.6% [130/8077], $P < 0.001$).

Figures 2 and 3 show the expected and actual number of donors at non-DonateLife hospitals in each of the 4 regions of Australia and by hospital type, respectively.

## DISCUSSION

### Summary of Findings

Using routinely collected data from the ANZICS APD over a 6-year study period, we developed a tool which adequately estimated the expected number of organ donors within 71 hospitals which were part of the DonateLife Network. Application of the same prediction tool to 79 non-DonateLife hospitals identified a smaller potential for organ donation in these hospitals compared to the DonateLife Network hospitals with less expected donors (130 vs 1931) over the same period. There was significant variation around the country, with New South Wales and Queensland having greater numbers of expected donors in non-DonateLife hospitals than the other two areas. Despite a smaller pool of expected donors in the non-DonateLife hospitals, the actual number of donors (both brain dead and DCD) was even lower than predicted (75 vs 130), and lower in all hospital types other than rural and regional ICUs.

### Comparison to Published Literature and Implications for Australian Practice

Several Australian and international studies out of the United States, Canada, and Europe have attempted to develop techniques to predict potential organ donor numbers using a variety of data sources including similarly routinely collected data.[12,14,15,21-23] Most have focused on estimating the maximum potential donor pool,[15,17,24] whereas this technique

**TABLE 2.**

**Comparison of DonateLife and non-DonateLife hospitals**

| | DonateLife network hospitals (n = 71) | Non-DonateLife hospitals (n = 79) |
|---|---|---|
| No. ICU admissions | 459 006 | 270 859 |
| Tertiary | 292 428 (27 hospitals) | 9148 (2 hospitals) |
| Metropolitan | 85 295 (19 hospitals) | 40 907 (13 hospitals) |
| Rural/regional | 69 561 (21 hospitals) | 30 479 (14 hospitals) |
| Private | 11 722 (4 hospitals) | 190 325 (50 hospitals) |
| ICU admission and diagnostic criteria (% of all ICU admissions) | | |
| Cancer related acute/chronic conditions | 54 637 (12%) | 44 150 (16%) |
| Admission due to neurological diagnosis | 44 780 (10%) | 8257 (3%) |
| Admission due to cardiac arrest | 13 093 (3%) | 2140 (1%) |
| No. deaths in ICU (% of all ICU deaths) | | |
| All hospital types | 33 614 | 8077 |
| Tertiary | 22 204 (66%) | 514 (6%) |
| Metropolitan | 6823 (20%) | 2593 (32%) |
| Rural/regional | 4335 (13%) | 1431 (18%) |
| Private | 252 (1%) | 3539 (44%) |
| No. deaths within each age group (% of all ICU deaths) | | |
| <60 y | 9039 (27%) | 731 (9%) |
| 60-70 y | 5690 (17%) | 779 (10%) |
| 70-80 y | 6381 (19%) | 1279 (16%) |
| 80+ y | 12 504 (37%) | 5288 (65%) |
| No. deaths which met organ suitability criteria at ICU admission (% of all ICU deaths) | | |
| Lung | 7709 (23%) | 1226 (15%) |
| Kidney | 9534 (28%) | 1592 (20%) |
| Liver | 10 402 (31%) | 1252 (16%) |
| Heart | 10 205 (30%) | 1105 (14%) |
| No. "ICU deaths potentially suitable to be donors" (% of all ICU deaths) | | |
| | 6835 (20%) | 452 (6%) |
| No. organ donors (% of all deaths) | 1992 (6%) | 75 (1%) |

*P* values for all comparisons between DonateLife and non-DonateLife hospitals <0.001.

**TABLE 3.**

**Numbers of "ICU deaths potentially suitable to be donors," expected donors and actual donors at DonateLife hospitals by region and year**

| | ICU deaths potentially suitable to be donors | Expected numbers of organ donors | Actual numbers of organ donors |
|---|---|---|---|
| Regions | | | |
| New South Wales | 1812 | 524 | 526 |
| Other | 1925 | 556 | 613 |
| Queensland | 1394 | 403 | 362 |
| Victoria | 1704 | 492 | 491 |
| Hospital type | | | |
| Tertiary (n = 27) | 5281 | 1526 | 1605 |
| Metropolitan (n = 19) | 973 | 281 | 218 |
| Rural/regional (n = 21) | 577 | 167 | 166 |
| Private (n = 4) | 4 | 1 | 3 |
| Year | | | |
| 2010 | 1100 | 318 | 286 |
| 2011 | 1109 | 320 | 307 |
| 2012 | 1088 | 314 | 319 |
| 2013 | 1104 | 319 | 347 |
| 2014 | 1239 | 358 | 346 |
| 2015 | 1195 | 345 | 387 |
| Total (all regions and hospital types, 2010-2015) | 6835 | 1975 | 1992 |

$\chi^2 = 10.0$, $P = 0.040$ for differences across regions.
$\chi^2 = 22.2$, $P < 0.001$ for differences across hospital types.
$\chi^2 = 11.5$, $P = 0.07$ for differences across years.

provides a realistic estimate of expected donor numbers. The conversion of potential to actual donors, which is approximately 50% in Australia[4] is dependent on the general and organ-specific suitability of potential donors after extensive individual assessment, and other factors, such as families declining the opportunity to donate. In our study, the number of actual donors (within the DonateLife hospitals) was approximately one third of deaths classified "ICU deaths potentially suitable to be donors." The remaining deaths which did not become donors are likely to include patients in whom a medical contraindication to donation was present but could not be identified in the ANZICS APD, patients who were not able to be physiologically supported for the timeframe to facilitate donation, patients whose families declined donation, as well as patients in whom the opportunity for donation was not offered or recognized by ICU staff.

Our study suggests that the potential for organ donation is greatest in the DonateLife network of hospitals and supports the current approach of targeting these sites. However, there appears to be a small, but underrecognized and underutilized pool of potential organ donors in non-DonateLife affiliated hospitals, predominantly in metropolitan and private hospitals. Data after Spanish and German reforms that greatly improved their donation rates to world leading status showed that an increase in donation at similar smaller centers was a significant factor.[25,26]

Factors unique to the Australian setting, such as geography, distribution of the population and the hospital system may limit wider applicability. However, given predictive ability relied solely on patient characteristics and hospital factors had little effect, this technique may be applicable to many countries with established intensive care systems and registry databases, and also facilitate comparison between countries with different donation systems.

This technique may also be used to monitor and investigate variation in donor numbers over time. For instance, an increase in actual donation rates might be due to an increase in overall numbers of medically suitable patients who die in Australian ICUs, and would in turn be reflected by a proportionately similar change in the predicted pool of expected donors. In contrast, changes in donation practices leading to improved identification of donors and consent rates would see an increase in actual donor numbers relative to the expected numbers predicted by this tool.

This technique may also facilitate targeted implementation of interventions to improve education, identification and referral, audit of all potential donation opportunities, and provision of resources, logistics, and personnel. It may then also allow hospitals and jurisdictional funding agencies to compare expected and observed donor numbers to assess cost effectiveness of initiatives and aid future planning.

## Strengths

This technique has been developed using a large data set from the ANZICS APD, which is a well-respected registry

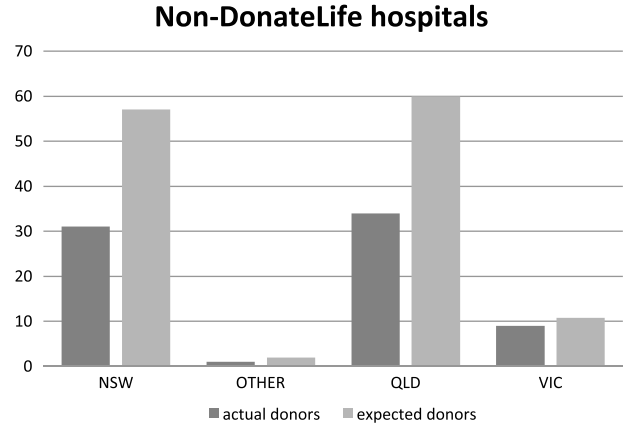


**FIGURE 2.** Actual and expected numbers of organ donors in non-DonateLife Hospitals within each region.

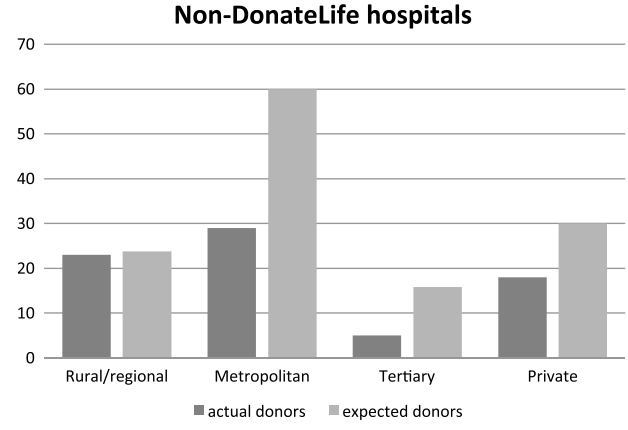


**FIGURE 3.** Actual and expected numbers of organ donors in non-DonateLife Hospitals by hospital type.

and has been used in other high-quality studies.[27,28] Similarly, the ANZOD database provides high quality data collected by dedicated and trained staff. A 2015 audit of all deaths in a large Australian hospital confirmed that almost all potential donors died in the ICU setting.[29] This supports the use of the ANZICS APD as a robust source to estimate the total number of expected organ donors in Australia. Utilizing routinely collected data from the APD not only allows for monitoring of the DonateLife audit's performance but also may limit bias which can occur in such specific audits, minimize duplication of data collection, and potentially improve use of time and resources. It also provides a method for predicting organ donor numbers in a much wider population that previously was poorly monitored. The ANZICS APD captures 150 Australian ICUs compared with 71 in the DonateLife audit. Although the gold standard to identify the individual reasons why an otherwise suitable patient may not become a donor remains an audit of charts and notes, as demonstrated by Sheehy et al,[15] this method has the potential to identify hospital types and regions that might be targeted to improve organ donation rates.

### Limitations

Due to the nature of data collection for the ANZICS APD, this prediction model can only be applied retrospectively and therefore a lag time in detection of changing donor numbers may occur. The APD provides only population-level data that limits its clinical applicability to an individual patient. Additionally, data is only collected for the first 24 hours of each ICU admission. Changes in the patient's clinical status or other information that impacts their potential for donation may become apparent outside of this window. For example, it is possible that a patient may be admitted with 1 primary diagnosis (eg, drug overdose) but die from another condition (eg, hypoxic brain injury) and may therefore not be picked up by our tool. Also, there are no specific data available on brain death in the database.

The criteria used to identify "ICU deaths potentially suitable to be donors" did not include nonneurological diagnoses, other than "cardiac arrest" and may thus miss potential DCD donors that die from other causes. It is likely that ongoing growth in DCD donors in patient groups who do not have neurological injuries[30] may limit the future applicability of this technique, although reassessment and modification of this model to more accurately estimate potential donor numbers may be possible as new data emerges.

Further work will be required to assess if the use of a single simple predictive ratio calculated by multiplying the number of "ICU deaths potentially suitable to be donors" by 0.2889, is equally applicable within all hospital types, or whether this will remain accurate with changes in donation practices over time. Future studies should also consider pediatric ICUs within Australia who all contribute to the Australian and New Zealand Paediatric Intensive Care Registry.

This technique has not been prospectively validated and thus requires further testing. Prospective application with a historical review of death records and data on concurrent donation activity should be performed and would be beneficial in refining the predictive model to determine whether there are indeed additional potential donors in the hospitals which are not part of the DonateLife Network. This would also aid in establishing significance for a wider international audience.

## CONCLUSIONS

It is possible to estimate the expected numbers of organ donors using routinely collected data from the ANZICS APD. Although the majority of predicted donors appeared to be in DonateLife Network hospitals, there appeared to be a smaller and under-utilized pool of potential organ donors in non-DonateLife hospitals that may represent an important target for future efforts to increase organ donor rates.

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