Example Material Shared with Expert Panel

1. Pre reading for first expert panel meeting in June 2015 (pages 2 – 16)

2. Pre reading for second expert panel meeting in February 2016 (pages 17 – 22)

3. Consultation on final risk factors April 2016 (pages 23 – 29)

Pre-reading for PRAiS 2 expert panel – July 2015

Contents

Background

In April this year we started a 15 month NIHR funded project to updated the PRAiS risk model for 30-day mortality after paediatric cardiac surgery with better information about comorbidities. In what follows "PRAiS 1" refers to the risk factors in the current version of PRAiS used in the UK and "PRAiS 2" refers to the updated risk model we are developing as part of this project.

Data completeness and quality for comorbidity information in the original 2000-10 dataset used to develop PRAiS 1 was poor. Although we explored different methods for incorporating information about different types of comorbidity and multiple comorbidity as part of our original project, none of the models using such methods proved to be robust. Faced with the choice of excluding comorbidity entirely as a risk factor or using a very crude measure of comorbidity as a "yes/no" variable, we chose the latter. This was because the definite presence of at least one non-Down syndrome comorbidity was significantly associated with mortality in multivariate analysis, comorbidity was considered extremely important in risk adjustment by clinical collaborators and it was hoped that inclusion of the crude risk factor would drive future improvement in data quality concerning comorbidities. The reporting of comorbidity has become much more complete (almost doubling since 2009) and we are now in a position to revisit how we use information about comorbidity for PRAiS 2.

Risk factors within PRAiS

The following pieces of information are risk factors within PRAiS 1:

- Specific procedure (including a "low volume" category for ten very rare procedures) – 31 total categories
- Procedure type (bypass/non-bypass)
- Univentricular heart status (yes/no)
- Age (continuous)
- Weight (continuous)
- Age bands (neonate, infant, child)
- Diagnosis risk group (low, medium, high)
- Non-down's comorbidity (yes/no)

For PRAiS 2 we are **not** looking to add new risk factors to these, since this set of factors was the result of careful and validated analysis for PRAiS 1. However, we **are** looking to see if changing the level of detail within the risk factors (in particular comorbidity) improves performance of the model for PRAiS 2.

However, the raw mortality rate is low (<3%) so there is a practical **upper limit** to how many free parameters can be reasonably included in the model (about 40, the current number of total categories in the above list). Thus it is likely that including more detailed information about comorbidity will mean a trade-off in grouping together some other categorical risk factors, most probably the current 31 specific procedure groupings used within PRAiS.

Potential considerations are:

- Including more comorbidity categories
- Including more diagnostic categories
- Including categorical weight categories (eg <5kg).
- Reducing number of specific procedure categories (e.g. by grouping together procedures with very low mortality)

Role of the expert panel

Comorbidities are likely to have a complex impact on risk of death, depending on number of comorbidities present, particular combinations of comorbidity, age and other covariates. The options for dealing with comorbidity and any resultant trade-offs should not be decided only by the CORU analysts but also need input from the clinical community.

The case mix of units is different not only in terms of primary cardiac diagnosis but also by pattern of comorbid conditions. It is also possible that an intensive care consultant will see the risk of comorbidity differently from a surgeon who might see it differently from a cardiologist. Additionally, each procedure can have several comorbidities entered (typically up to 8) and there may be variations in coding practice between centres. Prematurity and/or extremely low weight babies are important comorbidities and there may be scope for inferring their presence from age and weight information in the absence of relevant comorbidity codes. Thus it is crucial to have input from a range of centres, a range of clinical expertise and experienced data managers who have an excellent understanding of how comorbidities are actually coded within the data. To this end we have assembled an expert advisory panel of nine people (you!) from five centres comprising three surgeons (Victor Tsang, David Anderson and David Barron), two cardiologists (Kate English and Rodney Franklin), two intensivists (Kate Brown and Shane Tibby) and two data management experts (Thomas Witter and John Stickley).

We want your thoughts on:

- Options to include more comorbidity categories (building on the work you've already done on Kate's categorisations in May and June)
- how to account for multiple comorbidities (e.g. do we add a comorbidity count variable or use a ranking system as for diagnosis?)
- how different are hospitals likely to be in how they allocate comorbidity codes to patients?
- should we include more diagnosis category information?
- Are there particular comorbidities we should treat individually (building on recent work done by Jeff Jacobs in the US)?
- Should we use weight to determine risk from being a small baby?
- Can we reduce specific procedure groups? (e.g. what would we lose by grouping together all procedure categories that have mortality rate of less than 0.1%?)

We will then go back to the data and statistics to test the various strategies suggested in the meeting and share with you how they perform from a statistical point of view.

Descriptive analysis of risk factors and mortality rates seen in NCHDA data from April 2009 – March 2014.

The below analysis comprises all relevant clean NCHDA data from April 2009 to March 2014. Table 1 shows records removed from analysis. Note that we have removed about 3400 records that have a potential anomaly (e.g. age or life status anomaly) – these records are currently with NICOR for advice. Since some records with a death recorded have been temporarily removed to check anomalous data, the observed mortality in the remaining clean dataset is likely slightly lower than the actual mortality. The total number of clean episodes used for the analysis below is 20,276.

Record Type	Number of Records
Original data set	**128,058**
Adults removed	-30,681
Pre April 2009 procedures removed	-57,954
Non-cardiac procedures removed	-2,016
Data anomalies *temporarily* removed	-3,372
Trivial procedures removed	-784
Hybrids/Other procedure types removed	-363
Catheter procedures removed	-11,825
Reoperations within 30 days removed	-654
Missing 30 day life status removed	-133
Remaining 30 day surgical episodes	**20,276**

Table 1 Records removed from the data set before analysis below

Number of episodes and observed 30-day mortality by data year

The number of episodes is relatively constant from year to year with mortality around 2.5%. The final year has lower mortality but this is likely due to the removal of life status anomalies disproportionately affecting the most recent year of data (30% of these anomalies had operations since Jan 2013 and mortality in Apr 13 – Mar 14 with anomalous records included is close to 2.5%).

NICOR Reporting Year	Alive	Dead	Survival (%)	Mortality (%)	Total
1:Apr 09 - Mar 10	3690	89	97.6%	2.4%	3779
2:Apr 10 - Mar 11	4131	109	97.4%	2.6%	4240
3:Apr 11 - Mar 12	4091	99	97.6%	2.4%	4190
4:Apr 12 - Mar 13	3895	81	98.0%	2.0%	3976
5:Apr 13 - Mar 14	4032	59	98.6%	1.4%	4091

Table 2 - mortality rate and number of surgical episodes by reporting year

Number of episodes and observed 30-day mortality by UVH status

UVH episode	Alive	Dead	Total	Mortality (%)	Frequency (%)
0: No	16999	314	17313	1.8%	85.6%
1: Yes	2803	121	2924	4.1%	14.4%

Table 3 - mortality rate and number of episodes by UVH status

Number of episodes and observed 30-day mortality by age band

Age band	Alive	Dead	Total	Mortality (%)	Frequency (%)
1: Neonate (<30 days)	4145	237	4382	5.4%	21.6%
2: Infant (31 days - 1 year)	7996	141	8137	1.7%	40.1%
3: Child (1 -16 years)	7698	59	7757	0.8%	38.3%

Table 4 - mortality rate and number of episodes by age band

As expected, deaths occur disproportionally in the youngest children, particularly in the first month of life.

Number of episodes and mortality by Specific Procedure

The observed mortality rate, along with 95% confidence intervals, by specific procedure category is shown in Figure 1 in order of descending mortality.

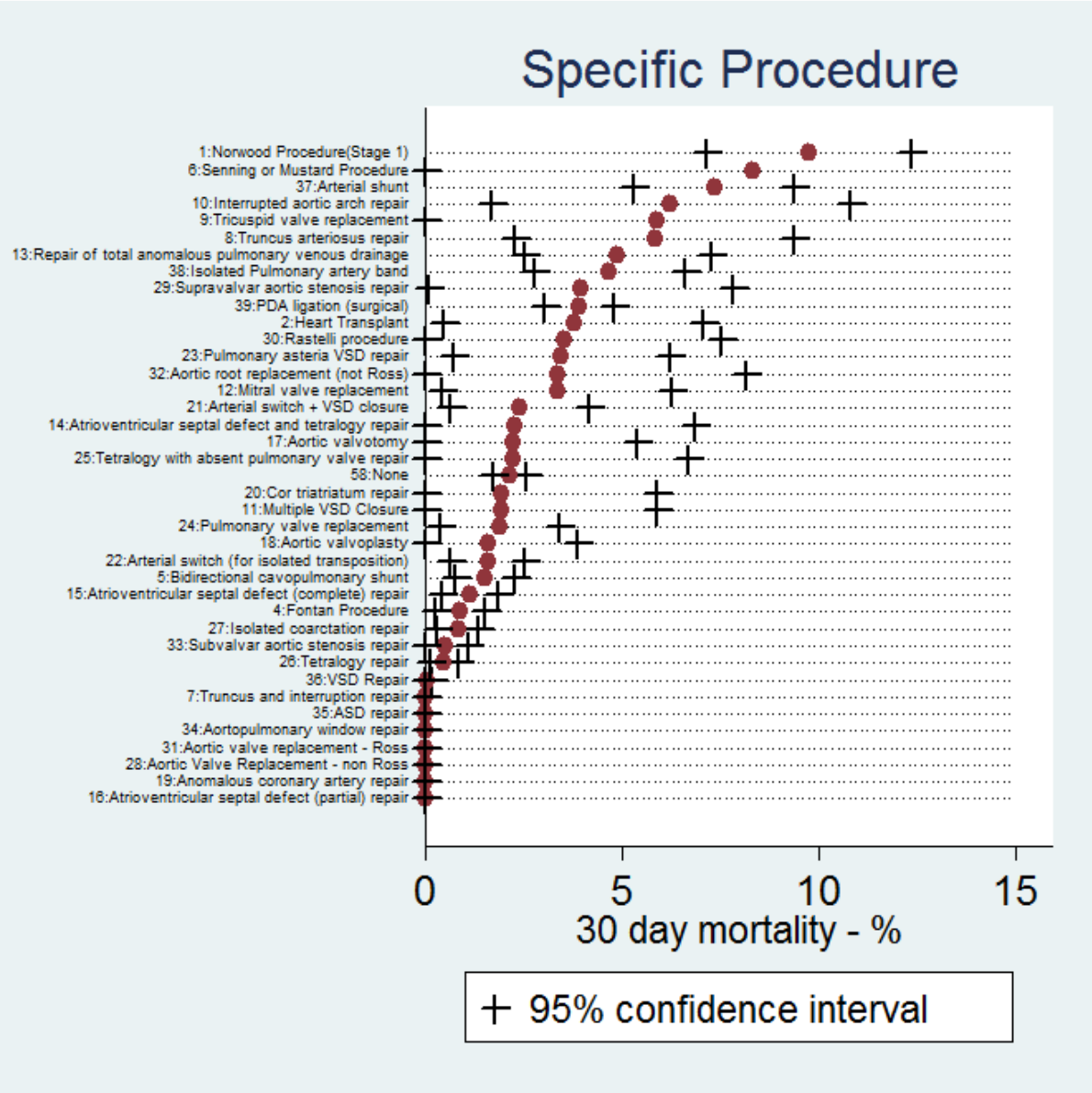


Figure 1 – mortality rate by specific procedure – excluding 3: TAPVD Repair + Arterial Shunt due to low volume

The corresponding table is shown below in Table 5. Potential inclusions into an updated "Low volume" category have been highlighted in yellow (<100 episodes over 5 years). Alternatively, low volume procedures with 0% observed mortality could go into a new "low risk" procedure category?

Specific Procedure	Alive	Dead	Total	Survival (%)	Mortality (%)	Frequency (%)
3:TAPVD Repair + Arterial Shunt	4	6	10	40.0%	60.0%	0.05%
1:Norwood Procedure(Stage 1)	453	49	502	90.2%	9.8%	2.48%
6:Senning or Mustard Procedure	11	1	12	91.7%	8.3%	0.06%
37:Arterial shunt	592	47	639	92.6%	7.4%	3.15%
10:Interrupted aortic arch repair	105	7	112	93.8%	6.3%	0.55%
9:Tricuspid valve replacement	16	1	17	94.1%	5.9%	0.08%
8:Truncus arteriosus repair	161	10	171	94.2%	5.8%	0.84%
13:Repair of total anomalous pulmonary venous drainage	310	16	326	95.1%	4.9%	1.61%
38:Isolated Pulmonary artery band	447	22	469	95.3%	4.7%	2.31%
29:Supravalvar aortic stenosis repair	97	4	101	96.0%	4.0%	0.50%
39:PDA ligation (surgical)	1812	74	1886	96.1%	3.9%	9.30%
2:Heart Transplant	127	5	132	96.2%	3.8%	0.65%
30:Rastelli procedure	82	3	85	96.5%	3.5%	0.42%
23:Pulmonary asteria VSD repair	167	6	173	96.5%	3.5%	0.85%
32:Aortic root replacement (not Ross)	57	2	59	96.6%	3.4%	0.29%
12:Mitral valve replacement	144	5	149	96.6%	3.4%	0.73%
21:Arterial switch + VSD closure	283	7	290	97.6%	2.4%	1.43%
14:Atrioventricular septal defect and tetralogy repair	43	1	44	97.7%	2.3%	0.22%
17:Aortic valvotomy	87	2	89	97.8%	2.2%	0.44%
25:Tetralogy with absent pulmonary valve repair	44	1	45	97.8%	2.2%	0.22%
58:None	4205	93	4298	97.8%	2.2%	21.20%
11:Multiple VSD Closure	50	1	51	98.0%	2.0%	0.25%
20:Cor triatriatum repair	50	1	51	98.0%	2.0%	0.25%
24:Pulmonary valve replacement	309	6	315	98.1%	1.9%	1.55%
18:Aortic valvoplasty	121	2	123	98.4%	1.6%	0.61%
22:Arterial switch (for isolated transposition)	673	11	684	98.4%	1.6%	3.37%
5:Bidirectional cavopulmonary shunt	970	15	985	98.5%	1.5%	4.86%
15:Atrioventricular septal defect (complete) repair	855	10	865	98.8%	1.2%	4.27%
4:Fontan Procedure	867	8	875	99.1%	0.9%	4.32%
27:Isolated coarctation repair	1184	10	1194	99.2%	0.8%	5.89%
33:Subvalvar aortic stenosis repair	581	3	584	99.5%	0.5%	2.88%
26:Tetralogy repair	1449	7	1456	99.5%	0.5%	7.18%
36:VSD Repair	1717	1	1718	99.9%	0.1%	8.47%
7:Truncus and interruption repair	10	0	10	100.0%	0.0%	0.05%
35:ASD repair	1002	0	1002	100.0%	0.0%	4.94%
34:Aortopulmonary window repair	35	0	35	100.0%	0.0%	0.17%
19:Anomalous coronary artery repair	91	0	91	100.0%	0.0%	0.45%
28:Aortic Valve Replacement - non Ross	87	0	87	100.0%	0.0%	0.43%
31:Aortic valve replacement - Ross	150	0	150	100.0%	0.0%	0.74%
16:Atrioventricular septal defect (partial) repair	391	0	391	100.0%	0.0%	1.93%

Table 5 - number of episodes and mortality by specific procedure grouping

Number of episodes and mortality by diagnosis grouping

The observed mortality rate, along with 95% confidence intervals, by diagnosis grouping is shown in Figure 2 in order of descending mortality. These diagnosis groups are more recent versions (2013/4) of the ones first developed by Kate Brown and Rodney Franklin in 2011/2 (Brown et al, CitY, 2013, 23:491-8). Each episode is assigned to a single diagnosis group which is the highest ranked of all diagnosis groups that patient could belong to, based on entered diagnosis codes for a record.

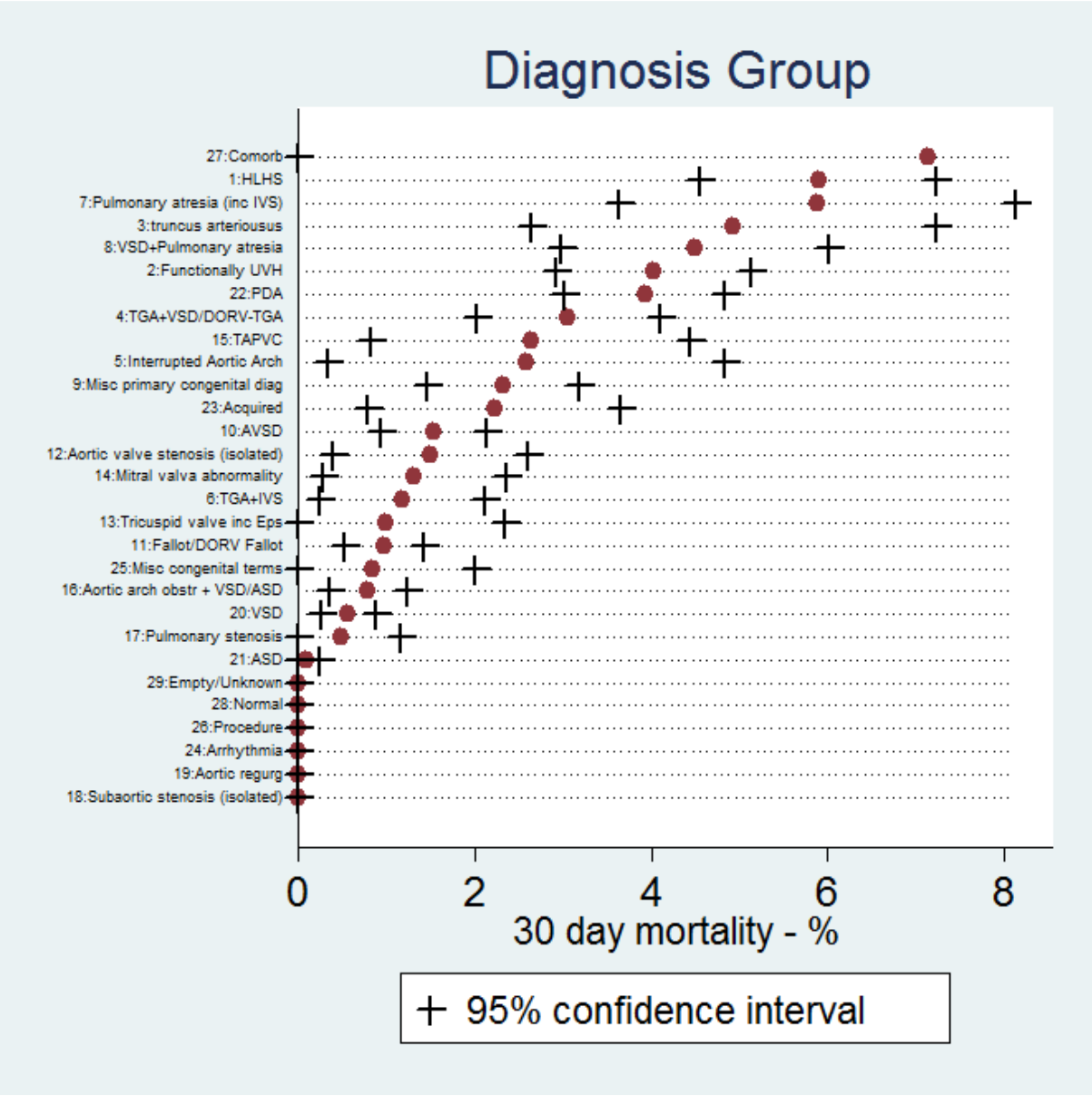


Figure 2 – mortality rate by diagnosis group

The corresponding table is shown below in Table 6. The different colours show allocation to the low, medium and high risk diagnosis groups used in PRAiS 1 (note that these allocations were made on an older version of these diagnosis groupings). Pink is high risk, yellow medium risk and green represents a low risk diagnosis. Two diagnosis groups are new and were not included in this allocation. The comorbidity category (if an episode only had comorbidity codes in its diagnosis fields) is now very rare (only 14 episodes) showing that recording of diagnosis has improved (similarly for

the procedure category and EMPTY/unknown). Its previous allocation to the low-risk group is no longer valid. Similarly the previous allocation of "procedure" category (where diagnosis fields only contain procedure codes) to "high risk diagnosis" no longer seems appropriate.

Diagnosis group	Alive	Dead	Total	Mortality (%)	Frequency (%)
27:Comorb	13	1	14	7.1%	0.1%
1:HLHS	1117	70	1187	5.9%	5.9%
7:Pulmonary atresia (inc IVS)	400	25	425	5.9%	2.1%
3:truncus arteriousus	328	17	345	4.9%	1.7%
8:VSD+Pulmonary atresia	680	32	712	4.5%	3.5%
2:Functionally UVH	1170	49	1219	4.0%	6.0%
22:PDA	1666	68	1734	3.9%	8.6%
4:TGA+VSD/DORV-TGA	1016	32	1048	3.1%	5.2%
15:TAPVC	296	8	304	2.6%	1.5%
5:Interrupted Aortic Arch	189	5	194	2.6%	1.0%
9:Misc primary congenital diag	1139	27	1166	2.3%	5.8%
23:Acquired	397	9	406	2.2%	2.0%
10:AVSD	1603	25	1628	1.5%	8.0%
12:Aortic valve stenosis (isolated)	460	7	467	1.5%	2.3%
14:Mitral valva abnormality	452	6	458	1.3%	2.3%
6:TGA+IVS	503	6	509	1.2%	2.5%
13:Tricuspid valve inc Eps	202	2	204	1.0%	1.0%
11:Fallot/DORV Fallot	1838	18	1856	1.0%	9.2%
25:Misc congenital terms	237	2	239	0.8%	1.2%
16:Aortic arch obstr + VSD/ASD	1511	12	1523	0.8%	7.5%
20:VSD	2307	13	2320	0.6%	11.4%
17:Pulmonary stenosis	414	2	416	0.5%	2.1%
21:ASD	1244	1	1245	0.1%	6.1%
28:Normal	4	0	4	0.0%	0.0%
18:Subaortic stenosis (isolated)	250	0	250	0.0%	1.2%
24:Arrhythmia	113	0	113	0.0%	0.6%
29:Empty/Unknown	21	0	21	0.0%	0.1%
19:Aortic regurg	215	0	215	0.0%	1.1%
26:Procedure	54	0	54	0.0%	0.3%

Table 6 - number of episodes and mortality by primary diagnosis group. Different colours show allocation to the low, medium and high risk groups used in PRAiS 1 (note that these allocations were made on an older version of these diagnosis groupings). Pink is high risk, yellow medium risk and green represents low risk. Two diagnosis groups are new and were not included in this allocation.

Based on Table 6 above, should we explore using more diagnosis groups within the risk model (instead of just low/medium/high risk)? For instance we could look at finer resolution of higher mortality diagnosis groups and keep a single "low risk diagnosis" group with mortality lower than, e.g. 0.5% or 1%? Alternatively, we could look to keep information about diagnoses that are more likely to be associated to "no specific procedure". About 20% of episodes cannot be allocated to a specific procedure group (see Table 5), and for these we will need to use information on diagnosis, age, weight and comorbidity to differentiate risk of death. The breakdown of diagnosis groups for "No Specific Procedure" episodes in descending order of frequency is shown in Table 7. It does appear that the most common diagnosis groups do have different associated mortality that could be useful for PRAiS2.

Diagnosis group for no specific procedures (N=4298)	Total number	Mortality (%)	Frequency (%)
20:VSD	495	1.0%	11.5%
9:Misc primary congenital diag	396	1.5%	9.2%
16:Aortic arch obstr + VSD/ASD	354	0.8%	8.2%
8:VSD+Pulmonary atresia	292	4.5%	6.8%
17:Pulmonary stenosis	288	0.0%	6.7%
21:ASD	246	0.4%	5.7%
11:Fallot/DORV Fallot	209	1.9%	4.9%
10:AVSD	206	2.4%	4.8%
14:Mitral valva abnormality	205	1.0%	4.8%
4:TGA+VSD/DORV-TGA	197	3.6%	4.6%
23:Acquired	197	3.0%	4.6%
2:Functionally UVH	183	7.1%	4.3%
25:Misc congenital terms	166	0.0%	3.9%
24:Arrhythmia	112	0.0%	2.6%
3:truncus arteriousus	110	3.6%	2.6%
7:Pulmonary atresia (inc IVS)	109	9.2%	2.5%
1:HLHS	100	6.0%	2.3%
13:Tricuspid valve inc Eps	95	0.0%	2.2%
12:Aortic valve stenosis (isolated)	75	5.3%	1.7%
22:PDA	51	0.0%	1.2%
6:TGA+IVS	48	4.2%	1.1%
19:Aortic regurg	46	0.0%	1.1%
5:Interrupted Aortic Arch	36	0.0%	0.8%
15:TAPVC	29	3.4%	0.7%
26:Procedure	27	0.0%	0.6%
27:Comorb	12	8.3%	0.3%
18:Subaortic stenosis (isolated)	10	0.0%	0.2%
29:Empty/Unknown	2	0.0%	0.0%
28:Normal	2	0.0%	0.0%

Table 7 - diagnosis groups associated with episodes with "no specific procedure" and corresponding mortality.

The breakdown of number of episodes and mortality using the existing low, medium and high risk diagnosis groupings (ie summarising Table 6 by colour) is shown in Table 8, but note that these mappings are not calibrated to this data set or these updated 26 diagnosis categories.

Diagnosis risk group	Alive	Dead	Total	Mortality (%)	Frequency (%)
1:High Risk Diagnosis	3749	193	3942	4.9%	20.8%
2:Medium Risk Diagnosis	10784	202	10986	1.8%	57.8%
3:Low Risk Diagnosis	4054	15	4069	0.4%	21.4%

Table 8 - number of episodes and mortality by diagnosis risk group. The colours match those given in Table 6.

Comorbidities

Number of episodes and mortality for comorbidities

The basic breakdown of comorbidities by "no comorbidities", "only Down's syndrome" and "any other comorbidity" is shown in Table 9. The positive coding of "no comorbidity" (using code 102000) has become much more common (at 20% of episodes, category 1 in the table), but this does seem to be unit-specific (about half of units do not use it).

Basic comorbidity breakdown	Alive	Dead	Total	Mortality (%)	Frequency (%)
0:nothing in comorbidity fields and no comorbidity codes in diagnosis fields	7447	99	7546	1.3%	37.2%
1:Patient has "no pre-procedural risk factors" recorded and nothing else	3943	40	3983	1.0%	19.6%
2:Patient has no *included* comorbidity codes (Kate's classification)	946	34	980	3.5%	4.8%
3:Patient has Down's and no other comorbs	1228	13	1241	1.0%	6.1%
4:Patient has at least one non-Down's comorb	6275	251	6526	3.8%	32.2%

Table 9 - basic breakdown of number of episodes and mortality for presence of comorbidity. Note that category 2 is patients who have codes entered in the comorbidity field but they are only codes classified as "do not include" in Kate's most recent classification.

As before, Down's syndrome is not associated with an increase in mortality but any other comorbidity (category 4) is associated with higher mortality. Category 2 in Table 9 represents patients who have had codes entered in the comorbidity field but they are only codes classified as "do not include" in Kate's most recent classification (e.g. aneurysms), but they **do** appear to be associated with elevated mortality. Is it worth considering these as a separate group?

There is also a marked increase in mortality for the number of comorbidities a child has, with a marked increase above 4 recorded comorbidities (see Table 10), although this does not represent many episodes.

Number of comorbidities	Alive	Dead	Total	Mortality (%)	Frequency (%)
0	12336	173	12509	1.4%	61.7%
1	4943	126	5069	2.5%	25.0%
2	1746	62	1808	3.4%	8.9%
3	564	45	609	7.4%	3.0%
4	189	12	201	6.0%	1.0%
5 or more	61	19	80	23.8%	0.4%

Table 10 - number of episodes and mortality by number of recorded comorbidities

Number of episodes and mortality by Kate's latest comorbidity groups

Table 11 shows the number of episodes and associated mortality by Kate's most recent comorbidity groupings (already commented on by you a few weeks ago). Note that a patient can be in more than one of the groups shown in the table, so that a patient who has comorbidity codes that put them in e.g. both "acquired comorbidity" and "congenital comorbidity" would be counted in both rows of Table 11.

Comorbidity Group		Alive	Dead	Total	Mortality (%)	Frequency (%)
Acquired cardiac diagnosis		704	41	745	5.5%	3.7%
Acquired comorbidity		2,914	173	3,087	5.6%	14.4%
Congenital comorbidity		2,187	80	2,267	3.5%	10.8%
Down's Syndrome		1,581	23	1,604	1.4%	7.8%
Premature		2,466	91	2,557	3.6%	12.2%
Not to include		2,185	100	2,285	4.4%	11.3%

Table 11 - number of episodes and mortality by presence of Kate's comorbidity groups

It is important to explore whether certain comorbidity groups are seen more often in combination in patients and what association combinations of groups have with mortality. Table 12 shows the 17 most common combinations of comorbidity groups seen in the dataset (including those where there is only one comorbidity group). So for instance, patients with **only** a congenital comorbidity are the most common group (6.6% of episodes) and the most common **combination** is patients with acquired comorbidity and prematurity (row 6 of Table 12).

The same information is shown in order of descending mortality in Figure 3, where the numbers on the vertical axis correspond to the row numbers given in Table 12.

We can see from Table 12 and Figure 3 that a congenital comorbidity on its own is associated with lower mortality than when it occurs in combination with another comorbidity, whereas acquired comorbidity patients are associated with relatively high mortality (over 5%) whether alone or in combination. How much should we try to take such structure into account in PRAiS 2? What are likely to be the most clinically important combinations and do these combinations tell us more than simply counting the number of recorded comorbidities?

	Acquired cardiac diagnosis	Acquired comorbidity	Congenital comorbidity	Down's Syndrome	Premature	Not to include	Total	Mortality (%)	Frequency (%)
1			■				1,331	2.55%	6.57%
2				■			1,203	1.08%	5.93%
3		■					1,176	5.19%	5.80%
4						■	979	3.47%	4.83%
5					■		878	1.25%	4.33%
6		■			■		453	5.08%	2.23%
7		■			■	■	432	5.32%	2.13%
8					■	■	307	1.95%	1.51%
9		■	■				302	3.31%	1.49%
10	■						276	2.54%	1.36%
11		■				■	176	6.82%	0.87%
12			■			■	143	3.50%	0.71%
13			■		■		109	3.67%	0.54%
14	■	■					104	6.73%	0.51%
15		■		■			96	3.13%	0.47%
16		■	■		■		76	3.95%	0.37%
17	■	■			■		64	10.94%	0.32%

Table 12 – episode number and mortality by common combinations of Kate's comorbidity groups

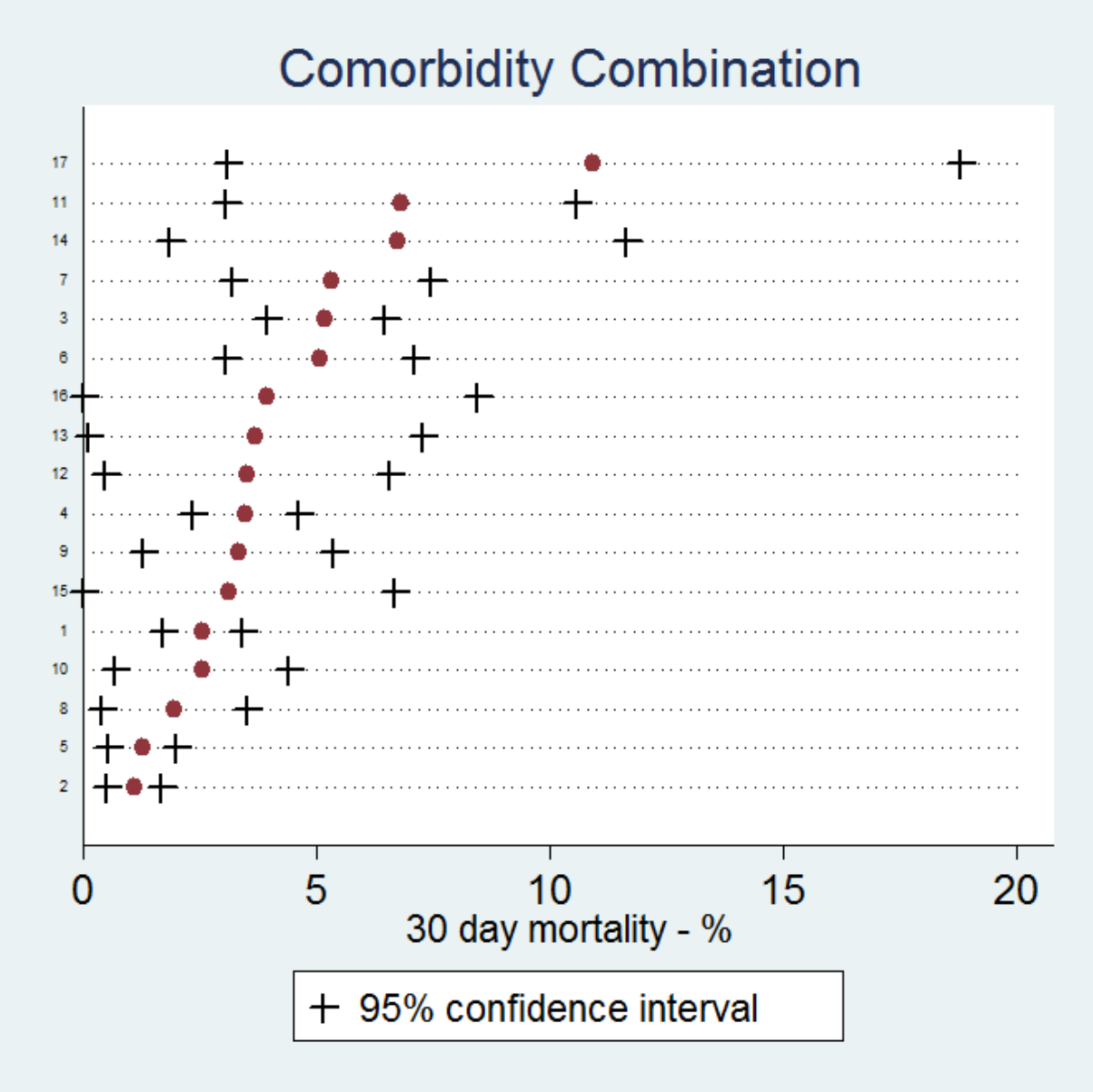


Figure 3 - episode number and mortality by common combinations of Kate's comorbidity groups sorted in order of descending mortality rate.

Common comorbidity codes

It is possible that very specific, individual, comorbidity codes might be strongly associated with mortality and common enough to consider as a separate factor. Table 13 shows the frequency and associated mortality of the twenty most commonly recorded comorbidity codes in the dataset, given in descending order of mortality.

Pre-procedural mechanical ventilation support is common (about 10% of episodes have this as a recorded comorbidity) and is associated with a high mortality rate (almost 7%). Presumably this is a marker of pre-procedural sickness – is it worth considering this as a separate risk factor? Also septicaemia and NEC are the two comorbidities associated with the highest mortality (11% and 7% respectively) but are both quite rare (around 1% of episodes). Do these warrant consideration for inclusions as separate comorbidities?

Twenty most commonly recorded comorbidities	Alive	Dead	Total	Mortality (%)	Frequency (%)
20:Pre-proc septicaemia	157	19	176	10.8%	0.9%
18:Necrotising enterocolitis	213	16	229	7.0%	1.1%
1:Pre-proc mech vent support	1,786	131	1,917	6.8%	9.5%
7:Pre-proc pulm hypertension	412	25	437	5.7%	2.2%
5:<2.5kg	1,970	112	2,082	5.4%	10.3%
8:Chromosonal anomaly	328	18	346	5.2%	1.7%
16:Heart failure	259	14	273	5.1%	1.3%
9:Pre-proc risk factor	270	14	284	4.9%	1.4%
4:Premature - less than 32 weeks	966	44	1,010	4.4%	5.0%
15:Cyanosis	230	10	240	4.2%	1.2%
17:22q11 microdeletion - CATCH 22	211	8	219	3.7%	1.1%
3:Premature	1,192	43	1,235	3.5%	6.1%
19:Renal abnormality	174	6	180	3.3%	0.9%
6:Premature - 32-25 weeks	404	13	417	3.1%	2.1%
11:Syndrome/association with cardiac involvement	251	8	259	3.1%	1.3%
10:Gastro-oesophageal reflux disease	309	8	317	2.5%	1.6%
12:Psychomotor development delay	232	4	236	1.7%	1.2%
13:DiGeorge sequence	228	4	232	1.7%	1.1%
14:Failure to thrive	463	8	471	1.7%	2.3%
2:Down's Syndrome	1,581	23	1,604	1.4%	7.9%

Table 13 - The 20 most common comorbidities, frequency and associated mortality rate. This table is sorted by descending mortality.

Comorbidities identified as risk factor by Jeff Jacobs

Jeff Jacobs explored the association of comorbidities with mortality after paediatric cardiac surgery in a recent paper using data from the US registry (Jacobs et al. Annals of Thoracic Surgery, 2014, 1653-9). We have tried as best as possible to investigate the frequency and associated mortality of the same comorbidities in the UK data set, including all comorbidities with the same name as those identified by Jacobs. However, it is important to note that how these comorbidity codes are actually allocated may differ markedly between the UK and US datasets – Rodney will probably have a better feeling for this!

Nonetheless, the frequency and associated mortality for 8 risk factors identified by Jacobs et al (2014) are shown in Table 14 below. Most of them are very rare in the UK data, but some, in particular Shock, Stroke and Renal dysfunction, are associated with high mortality.

Comorbidities identified by Jacobs	Alive	Dead	Total	Mortality (%)	Frequency (%)
2:Renal dysfunction	249	27	276	9.8%	1.4%
1:Shock	114	17	131	13.0%	0.6%
1.a:Shock - resolved	25	0	25	0.0%	0.1%
1.b:Shock - persistent	11	3	14	21.4%	0.1%
6:Neurological defect	108	5	113	4.4%	0.6%
3:Mechanical circulatory support	94	4	98	4.1%	0.5%
4:Coagulation	78	6	84	7.1%	0.4%
8:Seizures	46	1	47	2.1%	0.2%
7:Stroke	18	2	20	10.0%	0.1%
5:Hypothyroidism	7	0	7	0.0%	0.0%

Table 14 - The number of episodes and observed mortality for episodes that included comorbidities that correspond to those identified by Jacobs et al. (2014).

Pre-reading for PRAiS 2 expert panel – February 2016

Contents

Background

Following the previous expert panel meeting in July 2015, further work has been carried out in developing PRAiS 2, an updated risk model for 30-day mortality after paediatric surgery building on PRAiS 1. The main action points following the previous meeting were:

- To include more detail for comorbidities.
  During the meeting an allocation of comorbidity and diagnosis codes was determined for the following groups:
    - Congenital comorbidity
    - Acquired comorbidity
    - Prematurity
    - Downs Syndrome
    - Severity of illness indicator
    - Acquired cardiac diagnosis
- To develop new risk groupings for specific procedure and diagnosis
  With the aim to reduce the number of specific procedure categories (29 in PRAiS 1) and increase the number of diagnosis risk categories (3 in PRAiS 1).
- To develop a new way of treating age and weight, to incorporate their nonlinear relationship with risk in a continuous way, rather than the previous use of age bands.

Developments since previous expert panel meeting (July 2015)

- **Specific Procedures**
  NICOR has made updates to their specific procedure algorithm, which we have incorporated in our data. We are also now including HLHS hybrid procedures and a further change to how Ross-Konno procedures are allocated.
- **Data anomalies**
  A great deal of work has gone into reducing the number of anomalies excluded from the data set. We are now excluding fewer than 100 records, where the anomaly directly affects either a key model risk factor or the reliability of the 30 day outcome.
- **Specific Procedure and Diagnosis Risk Groups**
  The expert panel were sent possible risk groupings in November for both Specific Procedures and Diagnosis for comment. These risk groups were determined by looking at the age at which procedures were being performed and the risk associated with them.

- **Treatment of age and weight**
  We have developed a continuous, nonlinear treatment of both age and weight.
- **Acquired Cardiac Diagnosis Risk Factor**
  Kate Brown has been working on developing an acquired diagnosis risk factor (attached), based on the diagnosis and comorbidity code allocation from the previous expert panel meeting.

Descriptive analysis of risk factors and mortality rates seen in NCHDA data from April 2009-March 2014

Our analysis uses all relevant clean NCHDA data from April 2009 to March 2014. Table 1 shows the number of records removed prior to analysis, along with the reason for removal.

Record Type	Number of Records
Original data set	**128,058**
Adults removed	-30,750
Pre April 2009 procedures removed	-57,977
Non-cardiac procedures removed	-1,991
Duplicate procedures removed	-59
Trivial procedures removed	-1,093
Non HLHS Hybrids/Other procedure types removed	-377
Catheter procedures removed	-12,831
Reoperations within 30 days removed	-1,019
Unknown 30 day life status removed	-28
Missing weight removed	-3
Remaining 30 day surgical episodes	**21,930**

Table 1: Records removed from the data set prior to analysis

The remaining episodes (n = 21,930) formed the dataset used in all of the following analyses. In this clean analysis dataset, the overall 30 day mortality rate is 2.5%, with 545 deaths.

Number of episodes and mortality by Specific Procedure

Table 2 shows the frequency and 30 day mortality associated with each specific procedure and risk group for the primary risk allocation we have been considering, which includes an additional "very high risk child" group, as discussed in the expert panels' comments on the groupings. The names of the groups refer to the risk level and the age group at which most of the procedures take place. Possible adjustments to the group allocations include separating Arterial shunt into its own group, or separating out groups 8 and 9 further to reduce the spread in ages in the groups.

Specific Procedure Group	Frequency	Mortality
1: Very high risk neonate & infant procedures	**1499**	**9.6%**
1:Norwood Procedure(Stage 1)	588	10.7%
2:HLHS Hybrid Approach	42	16.7%
4:TAPVC Repair + Arterial Shunt	11	63.6%
8:Truncus and interruption repair	15	6.7%
22:Arterial switch + aortic arch obstruction repair (with-without VSD closure)	80	7.5%
47:Arterial shunt	763	7.9%
2: High risk neonate & infant procedures	**3399**	**4.2%**
9:Truncus arteriosus repair	191	5.8%
11:Interrupted aortic arch repair	120	5.8%
14:Repair of total anomalous pulmonary venous connection	332	5.1%
23:Arterial switch + VSD closure	311	2.6%
48:Isolated Pulmonary artery band	532	4.5%
49:PDA ligation (surgical)	1913	4.0%
3: Low risk neonate & infant procedures	**2001**	**1.2%**
24:Arterial switch (for isolated transposition)	724	1.5%
29:Isolated coarctation/hypoplastic aortic arch repair	1240	1.0%
40:Aortopulmonary window repair	37	0.0%
4: Very high risk child procedures	**481**	**5.0%**
7:Senning or Mustard Procedure	16	12.5%
15:Pulmonary vein stenosis procedure	95	6.3%
25:Pulmonary atresia VSD repair	201	4.5%
27:Tetralogy with absent pulmonary valve repair	49	4.1%
33:Ross-Konno procedure	48	4.2%
41:Unifocalised procedure (with/without shunt)	72	4.2%
5: High risk child procedures	**1680**	**3.0%**
3:Heart Transplant	152	3.3%
10:Tricuspid valve replacement	17	5.9%
13:Mitral valve replacement	169	4.1%
19:Aortic valve repair	292	2.1%
26:Pulmonary valve replacement	332	2.4%
35:Aortic root replacement (not Ross)	59	3.4%
36:Cardiac conduit replacement	167	2.4%

37:Isolated RV to PA conduit construction	399	3.5%
44:Tricupid valve repair	93	4.3%
6: Medium risk (younger) child procedures	**2421**	**1.7%**
6:Bidirectional cavopulmonary shunt	1157	1.6%
12:Multiple VSD Closure	59	1.7%
16:Atrioventricular septal defect and tetralogy repair	50	2.0%
17:Atrioventricular septal defect (complete) repair	894	1.1%
21:Cor triatriatum repair	55	3.6%
31:Supravalvar aortic stenosis repair	102	3.9%
32:Rastelli - REV procedure	104	2.9%
7: Low risk child procedures	**2271**	**0.7%**
5:Fontan Procedure	990	1.0%
34:Aortic valve replacement - Ross	165	0.6%
38:Subvalvar aortic stenosis repair	612	0.5%
39:Mitral valve repair	236	0.4%
43:Sinus Venosus ASD and-or PAPVC repair	268	0.4%
8: Medium risk infant & child procedures	**2162**	**0.6%**
18:Atrioventricular septal defect (partial) repair	397	0.5%
28:Tetralogy and Fallot-type DORV repair	1529	0.6%
42:Vascular ring procedure	236	0.4%
9: Low risk infant & child procedures	**2885**	**0.1%**
20:Anomalous coronary artery repair	94	0.0%
30:Aortic Valve Replacement - non Ross	94	0.0%
45:ASD repair	947	0.1%
46:VSD Repair	1750	0.2%
10: No Specific Procedure	**3131**	**2.8%**
58:None	3131	2.8%

Table 2: Number of episodes and mortality by specific procedure and grouping

Number of episodes and mortality by diagnosis

Table 3 shows the frequency and 30 day mortality associated with each diagnosis and risk group for the primary risk allocation we have been considering. Possible adjustments to the group allocations include incorporating some of the lower risk groups.

Diagnosis Group 1	Frequency	Mortality
1: Risk Group 1	**2317**	**6.5%**
1:HLHS	1399	6.6%
3:Truncus arteriosus	400	5.5%
7:Pulmonary atresia (inc. IVS)	518	6.8%
2: Risk Group 2	**2287**	**4.6%**
2:Functionally UVH	1436	4.5%
8:VSD+Pulmonary atresia	851	4.8%
3: Risk Group 3	**3433**	**3.6%**
4:TGA+VSD/DORV-TGA	1172	3.2%
5:Interrupted Aortic Arch	211	3.3%
15:TAPVC	299	2.7%
22:PDA	1751	4.0%
4: Risk Group 4	**1356**	**2.7%**
9:Miscellaneous primary congenital diagnosis	1356	2.7%
5: Risk Group 5	**765**	**2.7%**
13:Tricuspid valve abnormality (inc. Ebstein's)	220	3.2%
23:Acquired	445	2.5%
29:Empty/Unknown	100	3.0%
6: Risk Group 6	**3665**	**1.4%**
10:AVSD	1690	1.7%
11:Fallot/DORV Fallot	1975	1.1%
7: Risk Group 7	**1269**	**1.3%**
12:Aortic valve stenosis (isolated)	517	1.7%
14:Mitral valva abnormality	497	1.0%
25:Miscellaneous congenital terms	255	0.8%
8: Risk Group 8	**2126**	**1.1%**
6:TGA+IVS	543	1.8%
16:Aortic arch obstruction +/-VSD/ASD	1583	0.9%
9: Risk Group 9	**2832**	**0.6%**
17:Pulmonary stenosis	437	0.7%
20:VSD	2395	0.6%
10: Risk Group 10	**1880**	**0.1%**
18:Subaortic stenosis (isolated)	266	0.0%
19:Aortic regurgitation	218	0.0%
21:ASD	1270	0.1%
24:Arrhythmia	126	0.0%

Table 3: Number of episodes and mortality by diagnosis and grouping

Number of episodes and mortality by comorbidity

Table 4 shows the frequency and 30 day mortality associated with each comorbidity group.

Comorbidity	Frequency	Mortality
Acquired comorbidity		
No	20584 (93.9%)	2.2%
Yes	1346 (6.1%)	6.8%
Congenital comorbidity		
No	19475 (88.8%)	2.3%
Yes	2455 (11.2%)	3.7%
Severe illness indicator		
No	19691 (89.8%)	1.9%
Yes	2239 (10.2%)	7.5%
Premature		
No	19238 (87.7%)	2.3%
Yes	2692 (12.3%)	3.9%
Downs Syndrome		
No	20235 (92.3%)	2.6%
Yes	1695 (7.7%)	1.5%
Acquired cardiac diagnosis		
No	19119 (87.2%)	2.3%
Yes	2811 (12.8%)	3.6%

Table 4: Number of episodes and mortality by comorbidity groups

8 February meeting discussion points

- Finalising Specific Procedure and Diagnosis groupings.
- Discussion about Acquired Cardiac Diagnosis risk factors
- Review some example models and their performance
    - Comparison with PRAiS1
    - Performance in subgroups and across units
- Treatment of unreasonable and missing patient weights
- Treatment and allocation of HLHS hybrid procedures

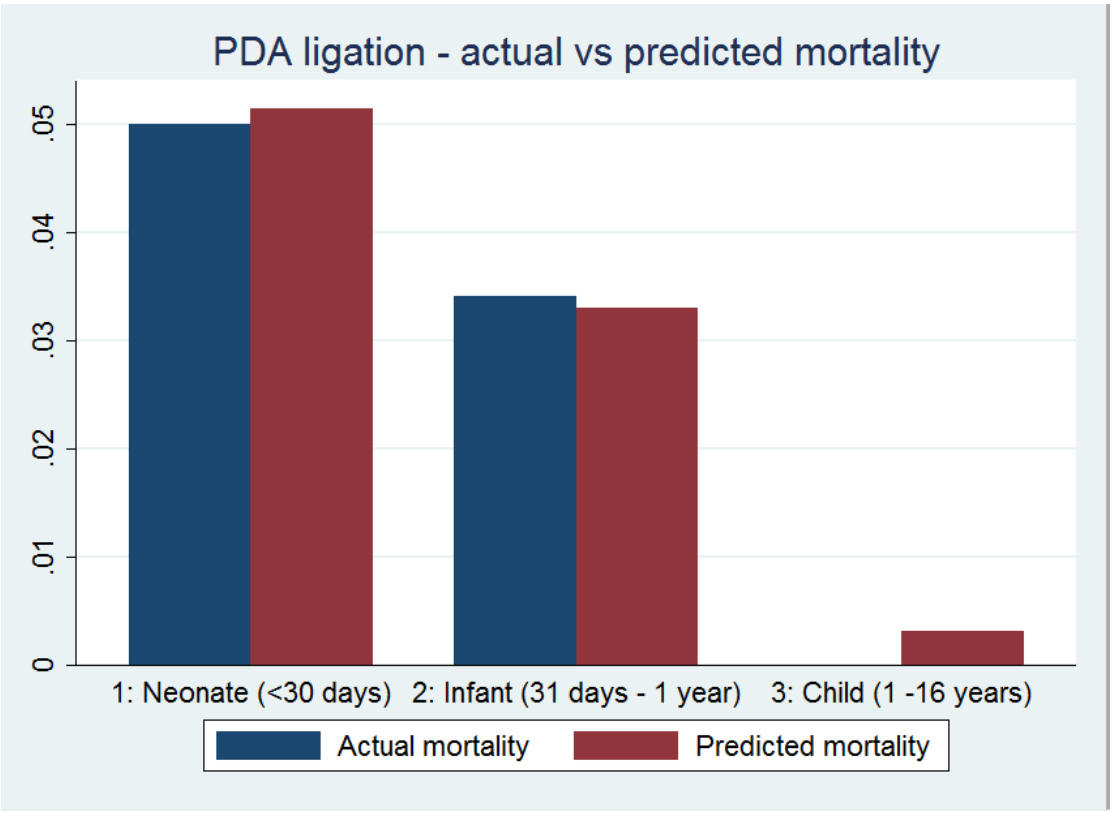
Summary of responses received to the our questions and our comments

Q1. Are you happy for us to work with Kate Brown to identify the very few remaining records with infeasible weight and the adjusting them manually to the mean weight-for-age value?

Everyone was happy for us to work with Kate on this although some thought there were some weights on the "boundary" of the extreme range (|z|>3) that should be looked at more closely. We are still working with Kate Brown to decide the best methodology for this.

Q2. Are you happy with the groupings for specific procedures and diagnoses? Are there any procedures or diagnoses in groups that you are concerned about?

- Pulmonary Atresia
  - In response to comments and further discussion, the diagnosis hierarchy has been amended so that patients will only be allocated to the (more severe) " Pulmonary Atresia (inc IVS)" group if they have the specific Pulmonary Atresia & IVS EPCC diagnosis code; patients with the generic Pulmonary Atresia diagnosis code will be allocated to "Pulmonary Atresia & VSD". Upon investigation of these patients in the data set, this corresponds best to how they are currently being coded.
- PDA Ligation
  - We looked into how well patients undergoing PDA ligation were being modelled, as John Stickley brought up that there are 2 distinct groups of patients undergoing this procedure, premature neonates and infants/children. We looked into these groups by comparing actual vs predicted % mortality (see below). The age and weight functions included in PRAiS2 appear to be going a good job of differentiating between these patients.



Q3. "Other illness" risk factors, in particular "Heart muscle problem or pulmonary hypertension": Possible gaming of new risk factors

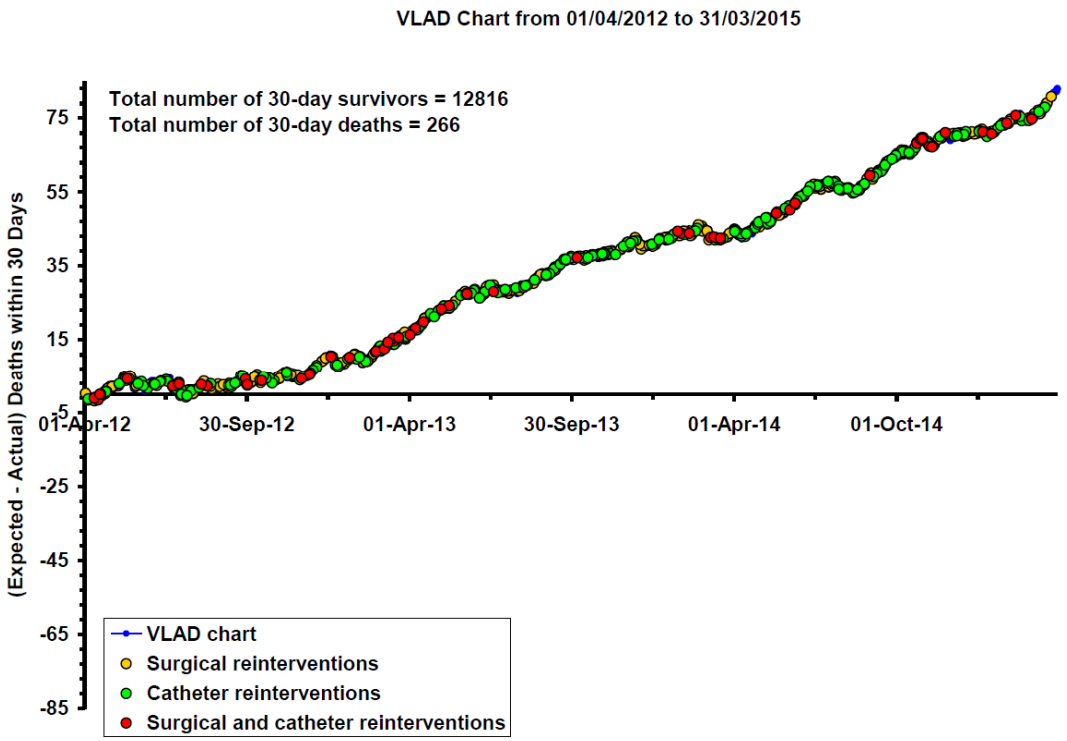
As some of the new risk factors include some quite generic codes there was some concern they might be gamed to improve risk-adjusted results. We cannot stop prevent this, but hope that it would not happen. However, NICOR could analyse changes in the rates of the risk factor reporting over time as part of its annual data analysis and this could be discussed at steering committee meetings if considered appropriate.

Q4. Questions about retrospective UVH allocation

Everyone was happy with this, so we will leave the latest UVH code allocation unchanged. There is a small chance that a few cases will be allocated incorrectly, but everyone agreed that these should be very rare.

Q5. Epoch effects & inclusion of a "post 2012" indicator in the risk model

General consensus was that the post 2012 flag should be included. This is now additionally corroborated by the recent NCHDA 2012-2015 report, which shows the current PRAiS risk model going out of date post 2012. We note that the last recalibration, although carried out in 2014, was done using national data from **April 2009 to March 2012.** You can see that the model was almost immediately out of date! We will thus include the 2012 epoch flag (set to 1 for 2013 onwards and 0 for 2012 and earlier).



Q6. Given the possible impact on one centre, are you still happy to include Hybrids in PRAiS2?

The general consensus was that Hybrid procedures should be included in PRAiS2. One of the possible solutions to the adverse effect this could have on the centre that currently performs the majority of Hybrid procedures would be to publish results both with and without the Hybrid procedures, which would be a decision for NICOR. Once there is more data on hybrids, we should be able to incorporate them better in any new recalibrations of PRAiS. It was also suggested, and we agree,

that there should be explicit acknowledgement of the underestimate of risk for hybrids HLHS procedures in the reporting of overall outcomes. We will certainly discuss this point in any publications and in the new PDF summary of the PRAiS2 risk model and its coefficients.

Q7. Given no major changes to the performance of this model based on responses to Q1-6, are you happy for us to proceed with testing this final model in the 2014-15 dataset?

People were happy for us to do this. We had some requests to look at differences in patient groups between PRAIS1 (current and what it would be if recalibrated on 2009-14 data) and PRAiS2 - we have included **examples** at the end of this document. We note that there are no major differences between PRAiS1 and PRAiS2 for broader risk groups – the biggest differences are (unsurprisingly) for children with many additional health problems, whose estimated risks are much higher in PRAiS2 compared to PRAiS1. We note that in general both versions of PRAiS calibrated on the 2009-14 dataset estimate lower risks than the version currently in use because the overall mortality rate has fallen to about 2% in recent years.

Q7. Institutional impact

Some people asked whether there was disproportionate impact on individual units. While we are trying not to look in detail at overall unit differences, there does not seem to be any disproportionate unit impact in moving from a (recalibrated) PRAiS1 to PRAiS2. Once we have the final version of PRAiS2, we could sit down with Rodney and look at impact on units with him in more detail if people felt that was appropriate.

Examples of differences between the original PRAiS 1, PRAiS 1 recalibrated on 2009-2014 data, and PRAiS 2

	Large changes in risk due to multiple comorbidities and additional risk factors, and changes in treatment of weight and age		Change in risk behaviour at PRAiS1 age band boundaries (no age bands in PRAiS2)	
	Patient A	Patient B	Patient C	Patient D
Age	3 days	2.5 months	11.5 months (infant)	1 yr 0.5 months (child)
Weight	2.5kg	2.7kg	8.7kg	7.8kg
Specific Procedure	Norwood Procedure	Truncus arteriosus repair	Bidirectional cavopulmonary shunt	Bidirectional cavopulmonary shunt
Diagnosis	HLHS	Truncus arteriosus	HLHS	HLHS
PRAiS1 only: Any non-Downs Comorbidity	Yes	Yes	No	No
PRAiS2 only: Congenital Comorbidity	Yes	No	No	No
PRAiS2 only: Acquired Comorbidity	Yes	Yes	No	No
PRAiS2 only: Heart muscle problems or pulmonary hypertension	Yes	Yes	No	No
PRAiS2 only: Severity of Illness indicator	Yes	Yes	No	No
Original PRAiS1 predicted Risk	**19.2%**	**5.1%**	**1.5%**	**1.2%**
Recalibrated PRAiS1 predicted risk	**18.6%**	**4.7%**	**1.3%**	**0.9%**
PRAiS2 predicted risk	**63.6%**	**29.7%**	**0.8%**	**1.4%**

	PRAiS 2 can discriminate between patients with different numbers of comorbidities			
	Patient E	Patient F	Patient G	Patient H
Age	7 yrs 10 months	8 yrs 1 month	1 yr 5 months	1 yr 5 months
Weight	21.2kg	21.2kg	8.3kg	8.3kg
Specific Procedure	Fontan Procedure	Fontan Procedure	Atrioventricular septal defect (partial) repair	Atrioventricular septal defect (partial) repair
Diagnosis	HLHS	HLHS	AVSD	AVSD
PRAiS1 only: Any non-Downs Comorbidity	Yes	Yes	Yes	Yes
PRAiS2 only: Congenital Comorbidity	Yes	No	No	No
PRAiS2 only: Acquired Comorbidity	Yes	Yes	Yes	No
PRAiS2 only: Heart muscle problems or pulmonary hypertension	No	No	Yes	Yes
PRAiS2 only: Severity of Illness indicator	No	No	Yes	No
Original PRAiS1 predicted Risk	**2.8%**	**3.0%**	**0.6%**	**0.7%**
Recalibrated PRAiS1 predicted risk	**2.5%**	**2.0%**	**0.8%**	**0.8%**
PRAiS2 predicted risk	**3.9%**	**2.0%**	**3.2%**	**0.9%**

	PRAiS2 can now discriminate better for extent of prematurity/low weight		PRAiS2 differentiates between comorbidity types whereas PRAiS1 does not.	
	Patient I	Patient J	Patient K	Patient L
Age	11 days	12 days	5 months	5 months
Weight	0.5kg	1.6kg	4.9kg	5.3kg
Specific Procedure	PDA ligation	PDA ligation	Atrioventricular septal defect (complete) repair	Atrioventricular septal defect (complete) repair
Diagnosis	PDA	PDA	AVSD	AVSD
PRAiS1 only: Any non-Downs Comorbidity	Yes	Yes	Yes	Yes
PRAiS2 only: Congenital Comorbidity	No	No	No	Yes
PRAiS2 only: Acquired Comorbidity	No	No	No	No
PRAiS2 only: Heart muscle problems or pulmonary hypertension	No	No	Yes	No
PRAiS2 only: Severity of Illness indicator	Yes	Yes	No	No
Current PRAiS1 predicted Risk	**6.3%**	**5.3%**	**2.8%**	**2.6%**
Recalibrated PRAiS1 predicted risk	**7.1%**	**6.6%**	**2.2%**	**2.1%**
PRAiS2 predicted risk	**8.0%**	**3.6%**	**2.1%**	**1.5%**

	For patients with fewer additional risk factors, the biggest change in risk arises from the recalibration, rather than changes between PRAiS 1 and PRAiS 2	
	Patient M	Patient N
Age	9 months	10 yrs 5 months
Weight	6.6kg	24.4kg
Specific Procedure	Tetralogy and Fallot-type DORV repair	No Specific Procedure
Diagnosis	Fallot/DORV Fallot	Fallot/DORV Fallot
PRAiS1 only: Any non-Downs Comorbidity	No	Yes
PRAiS2 only: Congenital Comorbidity	No	Yes
PRAiS2 only: Acquired Comorbidity	No	No
PRAiS2 only: Heart muscle problems or pulmonary hypertension	No	No
PRAiS2 only: Severity of Illness indicator	No	No
Current PRAiS1 predicted Risk	**0.7%**	**3.7%**
Recalibrated PRAiS1 predicted risk	**0.4%**	**2.1%**
PRAiS2 predicted risk	**0.5%**	**1.9%**