Survival of individuals with cerebral palsy born in Victoria, Australia, between 1970 and 2004

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ABBREVIATIONS

CI	Confidence interval
CP	Cerebral palsy
GMFCS	Gross Motor Function Classification System
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th revision
IQ	Intelligence Quotient

AIM This study used data collected prospectively since 1986 from a population-based cerebral palsy registry to explore the rates, predictors, trends, and causes of mortality for individuals born in Victoria, Australia, between 1970 and 2004.

METHOD Data were extracted for 3507 individuals (1972 males; 1535 females). The probability of survival before 31 May 2010 was determined using the Kaplan–Meier method; age-specific mortality rates were calculated per 1000 person-years and related to population rates. Using Cox proportional hazards regression, relative risks of mortality were estimated for different categories of chosen demographic and clinical variables. Causes were tabulated according to the direct cause of death.

RESULTS There were 418 deaths. Crude mortality was 20% at the age of 40 years. Relative to the population, mortality was highest in children aged under 15 years and decreased to twice the population rate at the age of 35 years. The strongest independent predictor of mortality was no independent ambulation (adjusted hazard ratio 6.2 [95% confidence interval 3.3–11.8]); additional predictors were severe intellectual impairment (3.0 [1.7–5.2]), epilepsy (1.4 [1.1–1.9]), deafness (2.6 [1.4–4.7]), and term birth (1.8 [1.3–2.4]). No improvement in survival was seen over time (unadjusted hazard ratio 1.00 [95% CI 0.99–1.01]). Respiratory causes were the most common direct causes of death.

INTERPRETATION Rates, predictors, and causes of death for individuals with cerebral palsy in Victoria were similar to those found in other population cohorts. Lack of improvement in survival since 1970 was an unexpected finding that warrants further investigation.

Cerebral palsy (CP) is a diagnostic label that embraces a range of disorders of movement and posture. Substantial variation exists with regard to the type, topographical pattern, and severity of the movement disorder, the presence of associated conditions and impairments, and how these combine to impact on function, participation, and quality of life. Since the label 'CP' accommodates such a wide variety of possible clinical manifestations, information about survival with CP based on different combinations of clinical features is needed to counsel families about a child's prognosis, to plan for the provision of medical, educational, and social services, to inform public policy, and for medicolegal services relating to litigation. The aim of this study was to describe the rates, trends, predictors, and causes of mortality in individuals with non-postneonatally acquired CP who were born in the Australian state of Victoria between 1970 and 2004.

A number of groups have previously studied life expectancy in CP samples but many studies have had shortcomings. Recent studies of all CP cases from long-standing registers in Western Australia,[1] the UK,[2] and Denmark[3] have provided useful information on the long-term prognosis of all newly diagnosed children. The UK study noted regional differences in survival, but it was unclear whether these reflected regional variation in survival patterns, risk factor profiles, levels of care, or differences in definition, classification, or ascertainment.[2]

Severity of disability is the key factor influencing survival in CP. Immobility or severe motor impairment of all four limbs,[1–9] intellectual impairment,[1,2,4–7,10] epilepsy,[3,4,10] severe visual and hearing impairments,[2,7,11] hydrocephalus,[4] and an increasing number of impairments[1,2,5–7] have been associated with poorer survival. Although different severity profiles have been used by each group to report survival in severely affected individuals, when children with similar patterns of abilities were compared, age-specific conditional survival estimates from the UK, Western Australia, and California were similar.[12]

There are a number of reasons to expect survival to have improved over the past half-century. Vigorous treatment of

infections, scoliosis surgery, advances in intensive care and ventilatory support, better antiepileptic medication, and a trend away from institutional care would all be anticipated to improve mortality.[1] Moreover, we now have a better understanding of the importance of appropriate nutritional status in individuals with severe disability, a greater appreciation of the risks of aspiration, improved surgical procedures for gastrostomy and fundoplication, and better gastrostomy feeding techniques. Despite these advances, most studies have reported no evidence of improved survival over the past two to three decades.[1,3,5–7,13,14] Only the Californian group has provided evidence of improvement, demonstrating significantly better survival for children who were largely immobile and fed by others, and adults dependent on gastrostomy feeding.[8]

Causes of death in CP have been reported by several groups and classified according to either underlying or direct causes of death.[1,4,5,9,11,15–17] All groups reported high frequencies of respiratory causes, although the proportions have varied widely depending on the methods used and characteristics of the cohort. The Californian group was the first to quantify cause-specific mortality risks for 4028 individuals with CP, finding an excess of cancer deaths, cerebrovascular disease in adults, intestinal obstruction and oesophageal diseases, and accidents and injuries.[17] Although some of these may relate to the initial cause of postneonatally acquired CP, the authors of the above paper discussed other possible explanations for some of these excess risks, including the effect of nulliparity on the risk of breast cancer, delay in cancer diagnosis due to communication difficulties, misdiagnosis of brain tumours as CP, and reduced physical activity increasing the risk of cerebrovascular disease.

METHOD

The study was conducted at the Royal Children's Hospital in Melbourne, Australia. Ethics approval for the project was granted by the hospital's Human Research Ethics Committee.

A total of 3507 individuals with non-postneonatally acquired CP (1972 males; 1535 females) born in Victoria between 1970 and 2004 were identified from the Victorian Cerebral Palsy Register. Data were extracted on demographics, gestational age (<28, 28–31, 32–36, 37+ completed wks), predominant motor type (spastic, ataxic, dyskinetic, hypotonic), topographical pattern (monoplegia/hemiplegia, diplegia/triplegia, quadriplegia), motor severity (mild, moderate, severe), intellectual status (none, mild/moderate, severe/profound), and the presence of epilepsy, blindness, deafness, and lack of speech. The Victorian Cerebral Palsy Register defines quadriplegia as involvement of all four limbs with the upper limbs at least as affected as the lower. Individuals with a predominantly dyskinetic or hypotonic motor type were deemed to have a quadriplegic pattern of motor impairment, whereas those with ataxia were classified as of unknown status. Individuals were defined as having mild motor impairment if they were independently ambulant at the age of 5 years (Gross Motor Function Classification System [GMFCS] levels I and II), as having moderate motor impairment if they were ambulant with the assistance of a hand-held mobility device in most indoor settings (GMFCS level III), and as having severe motor impairment if they had no independent ambulation (GMFCS levels IV and V), although they may have been able to walk short distances with physical assistance or when positioned in a body-support walker. A diagnosis of epilepsy was based on a history of two or more unprovoked seizures, excluding neonatal convulsions. For the sensory and cognitive variables, assessment of impairments was made by formal testing procedures or by clinical judgement when formal testing was not possible. If IQ testing was available, mild to moderate intellectual impairment was defined as an IQ of 30 to 69, and severe to profound as an IQ <30. Blindness was defined as corrected acuity worse than 6/60 in the better eye or no functional vision, and deafness as hearing loss of >70 dB based on the pure tone average in the better ear.

What this paper adds

- Individuals with CP had an 80% survival rate to the age of 40 years.
- No independent ambulation was the strongest predictor of mortality.
- Respiratory causes were the most common direct causes of death.
- No improvement in survival was seen between the 1970s and 2000s.

Deaths were ascertained through linkage with the Australian National Death Index, a register of all deaths in Australia since 1980, and searches of the Victorian Death Index for deaths before 1980. At the time of the latest linkage in June 2010, data on deaths were complete up to May 2010, whereas causes of death were available only for deaths before 2008. Only one underlying cause of death was coded until 1997, but since then multiple-cause coding has been used to code all morbid conditions, diseases, and injuries entered on the death certificate. Since 1997, causes of death have been classified according to the World Health Organization's International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10).[18]

Statistical analysis

Lifetimes were computed in days from birth until death or, for those still alive, until the chosen censoring date of 31 May 2010. For each year, the effective number at risk and the proportion who died was determined, and the probability of survival with its standard error was estimated and graphed using the Kaplan–Meier method. Crude mortality rates were calculated per 1000 person-years stratified by age in 5-year groups. Mortality rates for infants under the age of 1 year were estimated separately because of the high likelihood of under-ascertainment of infants who die before CP is diagnosed. Person-years were calculated by summing the number of years for which an individual was at risk of dying over all individuals in each 5-year stratum. Age-specific mortality rates were compared, as rate ratios, with mean population mortality rates of the mid-year age group for males and females for 2007 to 2009, as published by the Australian Bureau of Statistics.[19]

Using Cox proportional hazards regression, the relative risks of mortality associated with clinical and other variables were estimated. Severe motor impairment was subdivided by the number of additional impairments present from a possible five, comprising epilepsy, severe/profound intellectual impairment, blindness, deafness, and lack of speech. The

simultaneous effect of covariates on mortality was assessed using Cox proportional hazards regression using an exploratory forwards and backwards selection process. To assess temporal trends in survival, Kaplan–Meier curves were constructed for each decade and each year of birth and the size of any differences was estimated using unadjusted Cox proportional hazards regression for the whole cohort, for the subgroup with severe motor impairment, and for those with severe motor impairment and at least three additional impairments.

Causes of death were summarized and tabulated according to the direct cause of death. The frequencies with which CP, epilepsy, scoliosis, perinatal factors, and birth defects were mentioned on the death certificates as underlying, direct, or contributing causes of death were also calculated. For cause of death statements, CP was defined as ICD-9 343 or 344, or ICD-10 G80, G81, or G82.0 to G82.5. Causes of death were cross-tabulated with motor severity (severe vs mild-moderate) and age of death in four groups (<1, 1–9, 10–19, and 20+). Statistical analysis was conducted using Stata 11 (Stata Corp 2009, College Station, TX, USA).

RESULTS

Of the total cohort of 3507 persons, 418 were known to have died by 31 May 2010. The characteristics of the cohort are shown in Table I.

Mortality rates

The mortality rate for the whole cohort was 3% by the age of 5 years, 6% by the age of 10 years, 11% by the age of 20 years, 17% by the age of 30 years, and 20% by the age of 40 years (Fig. 1). When Victorian data were analysed conditional on survival to 2 years of age, the 20-year mortality was 10%. The percentages of survivors at 10, 20, 30, and 40 years of age by motor severity level and number of additional impairments from a possible five, comprising epilepsy, severe/profound intellectual impairment, blindness, deafness, and lack of speech, are presented in Table II.

Infants under 1 year of age had the highest mortality rate, at 8 per 1000 person-years, which is twice the population rate (Table III). At older ages, the rates were relatively constant, varying between 5 and 8 per 1000 person-years until the age of 35 years, when the crude mortality rate dropped to 2 per 1000 person-years. Age-specific mortality rates for individuals with CP were over 50 times the population rate between the ages of 5 and 15 years, but declined steadily to twice the population rate in the 35- to 40-year age group.

Predictors of mortality

Based on univariable analysis, many variables were predictive of a higher risk of mortality in this cohort (Table I). Compared with individuals with mild motor impairment, the mortality risk was over 30 times higher among individuals with severe motor impairment. A quadriplegic topographical pattern, hypotonic motor type, epilepsy, a severe/profound degree of intellectual disability, functional blindness, bilateral deafness, and lack of speech were also associated with higher mortality risk. On the other hand, an ataxic motor type and preterm birth were relatively protective. For the subgroup of individuals with severe motor impairment, stratification by the number of additional impairments revealed significantly different rates of mortality (Fig. 2). On multivariable analysis, severe motor impairment, lack of speech, deafness, severe/profound intellectual impairment, term delivery, and epilepsy all contributed to the risk of mortality independent of the other factors studied (Table IV). The differences between unadjusted and adjusted hazard ratios suggested that the effect of deafness was substantially unconfounded with other effects, in contrast to those of epilepsy, blindness, and lack of speech, for which the adjusted hazard ratios were substantially lower than the unadjusted.

Trends

For the whole cohort, there was no statistical evidence of a difference in mortality according to period of birth, whether calculated by year or decade (hazard ratio 1.00, 95% confidence interval [CI] 0.99–1.01). There was also no improvement in mortality according to decade of birth for individuals with a severe degree of motor impairment requiring wheeled mobility (hazard ratio 1.01, 95% CI 0.99–1.02) or for those with severe motor impairment and at least three additional impairments (hazard ratio 1.04, 95% CI 1.02–1.06).

Causes of death

No causes were available for 42 deaths that occurred after 2007 (data forthcoming) and an additional 40 deaths (data missing). For nearly half the remaining 336 deaths, diagnostic labels for the underlying condition were listed, but no direct causes of death were coded. This situation occurred less frequently with increasing age at death. A diagnostic code indicative of a diagnosis of CP was listed on the death certificate in 207 of 336 (62%) cases as either an underlying, direct, or contributing cause. Perinatal factors such as extreme preterm birth or birth asphyxia were listed in 11, birth defects in 42, scoliosis in 15, and epilepsy in 68 cases.

Direct causes of death are shown in Table V stratified by severity and age at death. For the 287 cases with severe motor impairment, respiratory disorders were listed as a cause of death on 107 death certificates. If diagnostic labels were included as the cause of death, 37% of deaths were attributed to respiratory causes; if only direct causes of death were considered, 74% deaths had respiratory causes. Respiratory causes included pneumonia, respiratory failure, influenza or lower respiratory tract infection, pneumonitis due to food and vomit, obstruction/asphyxiation from a foreign body, and other respiratory causes such as asthma and acute bronchiolitis. Among the 39 individuals with mild to moderate motor impairment at 5 years of age, respiratory causes of death were still common, but they were exceeded in frequency by accidental deaths, including six cases of drowning, and also cardiac causes.

DISCUSSION

For all known cases of non-postneonatally acquired CP in Victoria, our estimated 20-year survival of 89% (95% CI 87–

Table I: Characteristics of the total cohort of 3507 individuals with non-postneonatally acquired cerebral palsy, and relative risks of mortality based on different levels of these variables, Victoria, 1970–2004

Characteristic	Total (*n*=3507)	Deceased (*n*=418) (%)	Hazard ratio (95% CI)	*p*-value
Decade of birth				
1970s	826	164 (19.8)	1.00	0.895
1980s	957	129 (13.5)	0.92 (0.72–1.17)	
1990s	1164	98 (8.4)	0.93 (0.70–1.22)	
2000s	560	27 (4.8)	0.98 (0.63–1.52)	
Sex				
Male	1972	233 (11.8)	1.02 (0.84–1.24)	0.821
Female	1535	185 (12.0)	1.00	
Gestational age at delivery (wks)				
37+	2078	317 (15.3)	1.00	<0.001
32–36	540	55 (10.2)	0.62 (0.46–0.82)	
28–31	470	16 (3.4)	0.22 (0.13–0.36)	
<28	284	16 (5.6)	0.46 (0.28–0.76)	
Unknown gestation	135	14 (10.4)	–	
Motor type				
Spastic	3081	373 (12.1)	1.00	0.312
Ataxic	174	2 (1.2)	0.09 (0.02–0.36)	
Dyskinetic	150	22 (14.7)	1.16 (0.76–1.79)	
Hypotonic	64	14 (21.9)	2.34 (1.37–3.99)	
Unknown motor type	38	7 (18.4)	–	
Topographical pattern				
Monoplegia/hemiplegia	1066	23 (2.2)	1.00	<0.001
Diplegia/triplegia	979	20 (2.0)	0.97 (0.54–1.77)	
Quadriplegia	1250	366 (29.3)	14.78 (9.70–22.53)	
Unknown (mainly ataxia)	212	9 (4.2)	–	
Motor impairment				
Mild	1974	26 (1.3)	1.00	<0.001
Moderate	458	23 (5.0)	3.68 (2.10–6.45)	
Severe	1027	357 (34.8)	31.96 (21.46–47.60)	
Unknown severity	48	12 (25.0)	–	
Intellectual impairment				
None	1474	24 (1.6)	1.00	<0.001
Mild–moderate	846	45 (5.3)	2.83 (1.72–4.64)	
Severe–profound	641	271 (42.3)	27.60 (18.18–41.89)	
Unknown severity	295	38 (12.9)	10.82 (6.49–18.04)	
Unknown intellectual status	251	40 (15.9)	–	
Epilepsy				
No epilepsy	2158	103 (4.8)	1.00	<0.001
Epilepsy	1196	292 (24.4)	5.26 (4.20–6.58)	
Unknown	153	23 (15.0)	–	
Vision				
Not blind	3167	350 (11.0)	1.00	<0.001
Blind	88	21 (23.9)	3.25 (2.09–5.06)	
Unknown visual status	252	47 (18.6)	–	
Hearing				
Not deaf	3079	295 (9.6)	1.00	<0.001
Deaf	70	16 (22.9)	2.85 (1.73–4.72)	
Unknown hearing status	358	107 (29.9)	–	
Speech				
At least some speech	2225	42 (1.9)	1.00	<0.001
No speech	942	287 (30.5)	18.59 (13.45–25.70)	
Unknown speech status	340	89 (26.2)	–	

CI, confidence interval; '-', not calculated.

90%) was very close to the 88% seen in Western Australia[1] and the 86 to 92% reported from the UK.[2] Since CP is a diagnostic label that is usually applied only after weeks or months of observation and investigation, children who died in the first year or two of life are less likely to have been defined as having CP, and the number of deaths in this time period may be

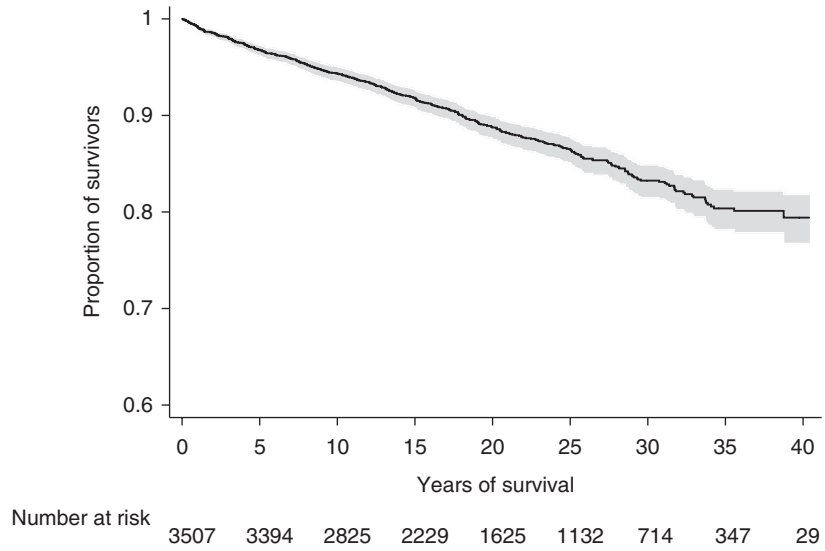

Figure 1: Kaplan–Meier survival curve showing survival to 40 years (95% confidence interval) in individuals with non-postneonatally acquired cerebral palsy born in Victoria between 1970 and 2004.

Table II: Percentage of survivors at 10, 20, 30, and 40 years by motor impairment severity and number of additional impairments from a possible five, comprising epilepsy, severe/profound intellectual impairment, blindness, deafness, and lack of speech

Motor severity+*n* of additional impairments	Beginning total	Total deaths	10y survival (95% CI)	20y survival (95% CI)	30y survival (95% CI)	40y survival (95% CI)
Mild+0	1478	14	99.9 (99.5–100.0)	99.2 (98.4–99.6)	98.3 (96.7–99.0)	97.7 (95.6–98.8)
Mild+1	378	7	99.2 (97.5–99.7)	99.2 (97.5–99.7)	97.9 (94.4–99.2)	95.1 (88.3–97.8)
Mild+2	77	1	100.0	98.4 (89.4–99.8)	98.4 (89.4–99.8)	98.1 (89.4–99.8)
Mild+3	41	4	95.1 (81.8–98.8)	95.1 (81.8–98.8)	88.8 (72.5–95.7)	88.8 (72.5–95.7)
Moderate+0	262	6	99.2 (97.0–99.8)	99.2 (97.0–99.8)	97.6 (90.7–99.4)	89.0 (73.7–95.7)
Moderate+1	100	7	95.9 (89.5–98.5)	93.5 (86.0–97.0)	90.7 (80.2–95.8)	90.7 (80.2–95.8)
Moderate+2	57	7	98.2 (87.6–99.7)	89.7 (74.4–96.1)	83.4 (66.3–92.3)	–
Moderate+3	39	3	100.0	94.4 (79.4–98.6)	91.4 (75.5–97.1)	–
Severe+0	156	19	91.0 (85.2–94.6)	90.1 (84.0–93.9)	83.5 (72.6–90.4)	–
Severe+1	222	52	86.3 (81.0–90.3)	78.0 (71.1–83.5)	68.7 (59.7–76.1)	56.8 (36.1–73.0)
Severe+2	297	104	79.8 (74.7–84.0)	68.0 (61.5–73.5)	52.1 (43.6–59.9)	–
Severe+3	352	182	80.7 (76.1–84.5)	51.7 (45.7–57.3)	35.3 (28.9–41.8)	30.8 (24.0–37.9)

CI, confidence interval; '-', not calculated.

Table III: Age-specific crude mortality rates and mortality ratios per 1000 person-years

Age (y)	*N* at risk	Person-years	*N* of deaths	Crude mortality rate (95% CI)	Population mortality rate	Mortality ratio (95% CI)
<1	3507	3494	29	8.3 (5.8–11.9)	4.4	2.1 (1.3–2.7)
1–4	3478	13 739	84	6.1 (4.9–7.6)	0.2	38.0 (30.9–47.3)
5–9	3394	15 668	80	5.1 (4.1–6.4)	0.1	56.8 (45.6–70.7)
10–14	2825	12 595	68	5.4 (4.3–6.9)	0.1	54.0 (42.6–68.5)
15–19	2229	9675	66	6.8 (5.4–8.7)	0.4	19.5 (15.3–24.8)
20–24	1625	6875	36	5.2 (3.8–7.3)	0.5	10.9 (7.9–15.1)
25–29	1132	4621	35	7.6 (5.4–10.6)	0.6	13.1 (9.4–18.2)
30–34	714	2632	18	6.8 (4.3–10.9)	0.7	9.2 (5.8–14.7)
35–39	347	987	2	2.0 (0.5–8.1)	0.9	2.2 (0.6–8.7)
40+	28	6	0	0.0	1.1	0.0

CI, confidence interval.

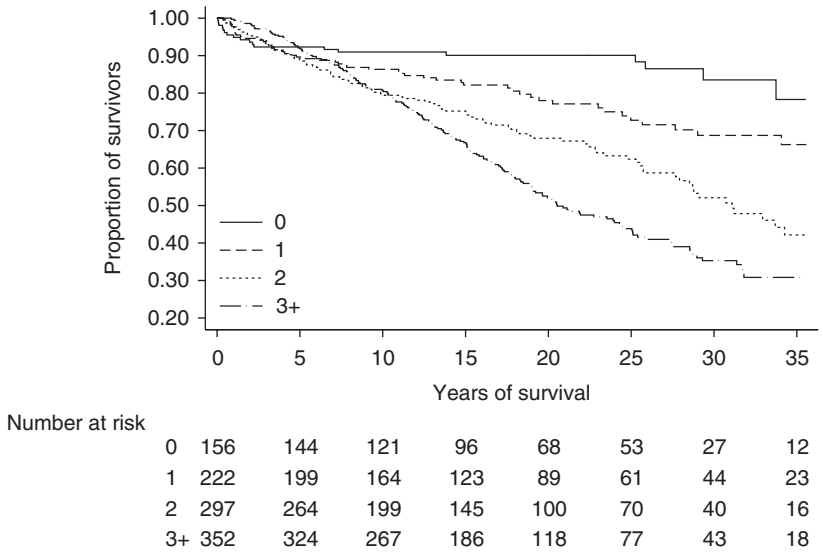

Figure 2: Kaplan–Meier survival curves showing 35-year survival in individuals with non-postneonatally acquired cerebral palsy and severe motor impairment by the number of additional impairments from a possible five, comprising epilepsy, severe/profound intellectual impairment, blindness, deafness, and lack of speech, between 1970 and 2004.

Table IV: Relative risks of mortality, unadjusted and adjusted for the other listed variables

Characteristic	Unadjusted hazard ratio (95% CI)	Adjusted hazard ratio (95% CI)	*p*-value
Gestational age at delivery (wks)			
37+	1.00	1.00	0.001
32–36	0.62 (0.46–0.82)	0.62 (0.42–0.90)	
28–31	0.22 (0.13–0.36)	0.42 (0.23–0.76)	
<28	0.46 (0.28–0.76)	0.71 (0.36–1.38)	
Term vs preterm birth			
Preterm birth	1.00	1.00	<0.001
Term birth	2.27 (1.79–2.88)	1.76 (1.29–2.40)	
Topographical pattern			
Monoplegia/ hemiplegia	1.00	1.00	0.346
Diplegia/ triplegia	0.97 (0.54–1.77)	0.97 (0.46–2.06)	
Quadriplegia	14.78 (9.70–22.53)	1.38 (0.71–2.67)	
Motor impairment			
Mild	1.00	1.00	<0.001
Moderate	3.68 (2.10–6.45)	1.51 (0.71–3.24)	
Severe	31.96 (21.46–47.60)	6.21 (3.28–11.77)	
Intellectual impairment			
None	1.00	1.00	<0.001
Mild–moderate	2.83 (1.72–4.64)	1.11 (0.62–1.97)	
Severe–profound	27.60 (18.18–41.89)	3.01 (1.74–5.22)	
Unknown severity	10.82 (6.49–18.04)	2.17 (1.11–4.26)	
Associated impairments			
Epilepsy	5.26 (4.20–6.58)	1.41 (1.05–1.91)	0.001
Blindness	3.25 (2.09–5.06)	0.94 (0.58–1.53)	0.934
Deafness	2.85 (1.73–4.72)	2.61 (1.44–4.741)	0.001
Lack of speech	18.59 (13.45–25.70)	2.59 (1.66–4.05)	<0.001

CI, confidence interval.

artificially low.[4,6,9,10] For this reason, the estimates from the UK were conditional upon survival to the age of 2 years, and when Victorian data were analysed using the same methodology, 20-year survival was 90%. Survival to 40 years was 83% in Western Australia and 80% in Victoria. Compared with Western Australian data of a decade earlier, crude mortality rates in Victoria were lower for children aged less than 10 years, but higher thereafter. Whether this suggests that deaths occurred at a later age in the more recent cohort is unclear from these limited data.

As with previous studies, we found a strong association between the severity of impairments and a higher risk of early mortality. With an adjusted hazard ratio of 6.2, lack of independent ambulation was the strongest independent predictor of mortality, an association that was first recognized in an Australian study in 1972.[20] Other factors that were independently associated with mortality in this cohort were severe/profound intellectual impairment, bilateral deafness, and epilepsy. In addition, greater risk was identified for individuals with severe motor impairment according to the number of additional impairments. These comorbidities are strongly correlated, and all act as markers for the severity of the brain injury. Although there has been some variation amongst studies on the strongest predictors of mortality, and it has not always been clear which ones pose an independent risk, most agree that a combination of factors provides the best prediction of survival. The factors included are to some extent dependent on the available data. In previous studies, the effect on survival of immobility and severe intellectual impairment has been shown to be independent of other factors,[4,10] while in our study epilepsy and bilateral deafness were also independent predictors. Earlier research has shown that epilepsy is associated with an increased risk of sudden death,[21] but death is seldom due to

Table V: Causes of death stratified by motor severity and grouped age at death

	Severe motor impairment, age (y)					Mild–moderate motor impairment, age (y)				
	n (%)					*n* (%)				
	<1	1–9	10–19	20+	All ages	<1	1–9	10–19	20+	All ages
Diagnostic label only	12	78	46	6	142 (49.5)	1	4	2	4	11 (28.2)
Respiratory										
Pneumonia	0	18	30	18	66 (23.0)	0	1	4	0	5 (12.8)
Aspiration/inhalation	0	6	8	16	30 (10.5)	0	0	0	0	0 (0.0)
Other	0	4	3	5	11 (3.8)	0	0	1	0	1 (2.6)
Other infections	0	6	1	0	7 (2.4)	0	0	0	0	0 (0.0)
Cancers	0	0	1	3	4 (1.4)	0	1	1	0	2 (5.1)
Other diseases										
Cardiac	0	1	0	1	3 (1.1)	0	1	0	5	6 (15.4)
Bowel	0	0	6	2	8 (2.8)	0	0	0	0	0 (0.0)
Liver	0	0	1	0	1 (0.4)	0	0	0	0	0 (0.0)
Renal	0	2	2	1	5 (1.7)	0	0	1	0	1 (2.6)
Injuries										
Accidental	0	3	2	0	5 (1.7)	0	3	1	3	7 (18.0)
Non-accidental	0	0	0	0	0 (0.0)	0	0	0	2	2 (5.1)
Other	0	3	2	0	5 (1.7)	0	1	1	2	4 (10.3)
All causes	12	121	102	52	287 (100)	1	11	11	16	39 (100)

seizures and may be indirectly associated with epilepsy through the side effects of antiepileptic drugs, including tiredness, somnolence, decreased mobility, and increased risk of fatal infections.[22] We are unable to provide an explanation for our finding of bilateral deafness as an independent risk factor.

Gestational age also predicted survival. Individuals born between 28 and 31 weeks' gestation had the best survival on univariable analysis, while those born at term had the worst survival. These findings are consistent with other reports.[1,2,7] Our data and data from the UK show that, for individuals with bilateral spastic CP, term birth is associated with more severe motor impairment than preterm birth, whereas the same association is not seen for unilateral spastic CP.[23] The association with severity would explain the results of the unadjusted analysis. However, when adjusted for other factors relating to the severity of impairment, the association between gestational age and survival remained statistically significant. Obviously there must be additional factors not accounted for in our analysis that may explain the results of the adjusted analysis, such as the degree of oromotor impairment. Oromotor function may be more impaired in individuals with bilateral cerebral grey matter patterns of injury as a result of perinatal asphyxia or cerebral malformations, which are more common in term-born infants.[24]

This study had some limitations in terms of the level of detail available for some of the factors included in the statistical modelling. The Victorian Cerebral Palsy Register lacks detailed information on the frequency, type, and control of seizures,[25] factors that have been reported to affect survival for individuals with a diagnosis of epilepsy.[14,22] Nor were we able to differentiate between cortical visual impairment and other visual pathologies.[26] It should also be noted that missing data may have affected our survival estimates, since data may have been missing because the severity of disability limited the testing.[25] This was particularly the case for data on intellectual impairment because precise measurement of IQ is difficult in the context of severe cognitive disability and concomitant sensory and motor disabilities. We did not present data on feeding, as tube feeding is an indicator that an individual has severe problems and a poor prognosis for survival, but it is also performed to improve survival and quality of life.[25]

Despite recent improvements in the care of individuals with CP, we were unable to show that survival had improved over time, either for the whole cohort or for more severely affected individuals. It is possible that in recent times more neonates with severe brain injury may have survived to an age where CP is diagnosed, and may have contributed to the number of early deaths, whereas previously the most severely affected infants may have died before identification. It is also possible that not enough time has elapsed to enable improvements to be seen on a population level, except in very large cohorts such as the one in California.

Causes of death can be difficult to study in a complex condition such as CP, as multiple factors may interact to bring about death. There is also a degree of subjectivity and variability in the assignment of underlying, direct, and contributory causes of death and, in some instances, the number of classified causes may be limited to just one underlying cause. This makes it difficult to quantify and compare direct causes of death and to assess whether CP contributed to the death. In our study, CP was listed as a cause in 62% of cases whereas other studies have reported much lower figures.[4,5,9,27] The proportion of deaths purported to have a direct respiratory cause in our study varied between 37% and 74% depending on whether we excluded cases in which only one underlying cause of death was provided. Previous studies have reported rates of between 15% and 78%.[4,17] We found a number of deaths related to accidental and non-accidental injury, and also to cardiac conditions, cancer, and bowel obstruction/disease, but because we did not relate our causes of death to the popu-

lation rates, it was not possible to make inferences about whether the age-specific risk of mortality from these causes is higher than expected for the general population.

CONCLUSION

The rates, predictors, and causes of death for individuals with CP in Victoria, Australia, are similar to those found in other population cohorts in developed countries. Contrary to expectation, no improvement in survival was seen over the 40 years of the study.

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