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The ORACLE Children Study: educational outcomes at 11 years of age following antenatal prescription of erythromycin or co-amoxiclav

Neil Marlow,1 Hannah Bower,2 David Jones,2 Peter Brocklehurst,1 Sara Kenyon,3 Katie Pike,4 David Taylor,5 Alison Salt6

ABSTRACT

Background Antibiotics used for women in spontaneous preterm labour without overt infection, in contrast to those with preterm rupture of membranes, are associated with altered functional outcomes in their children.

Methods From the National Pupil Database, we used Key Stage 2 scores, national test scores in school year 6 at 11 years of age, to explore the hypothesis that erythromycin and co-amoxiclav were associated with poorer educational outcomes within the ORACLE Children Study.

Results Anonymised scores for 97% of surviving children born to mothers recruited to ORACLE and resident in England were analysed against treatment group adjusting for key available socio-demographic potential confounders. No association with crude or with adjusted scores for English, mathematics or science was observed by maternal antibiotic group in either women with preterm rupture of membranes or spontaneous preterm labour with intact membranes. While the proportion receiving special educational needs was similar in each group (range 31.6–34.4%), it was higher than the national rate of 19%.

Conclusions Despite evidence that antibiotics are associated with increased functional impairment at 7 years, educational test scores and special needs at 11 years of age show no differences between trial groups.

Trial registration number ISRCT Number 52995660 (original ORACLE trial number).

INTRODUCTION

The ORACLE Children Study evaluated the outcome of children born to women who were entered into the ORACLE study and were randomly assigned to receive erythromycin, co-amoxiclav or placebo in two factorial trials relating to women in spontaneous labour with intact membranes (SPL)1 or with prelabour preterm rupture of membranes (PROM).2 Children whose mothers received antibiotics during SPL had an excess of impairments at 7 years, in contrast to those whose mothers were entered into the PROM arm of the trial. These data, however, are based on follow-up of 71% (SPL) and 75% (PROM), respectively, of the children born to mothers who took part.

Reports of long-term outcomes following perinatal trials aim for as complete ascertainment as is possible. One potential solution to this is to use nationally collected educational data. We have recently reported outcomes for 7-year-old children using Key Stage 1 (KS1) results.3 The disadvantage of these tests is that they represent the performance of the child based on teacher assessment and do not include pupils in all schools. In contrast, Key Stage 2 tests (KS2) are universal, standardised, nationally collected educational tests of English, mathematics and science, we demonstrate no differences in long-term educational outcomes at 11 years, or in special needs, following antenatal prescription of antibiotics.

While attainment test results are within national norms, special needs requirements among these children are higher.

The use of anonymised educational national data provides good coverage of the population and a robust middle childhood outcome.

What this study adds?

▸ Using independently collected and scored national attainment tests of English, mathematics and science, we demonstrate no differences in long-term educational outcomes at 11 years, or in special needs, following antenatal prescription of antibiotics.

▸ While attainment test results are within national norms, special needs requirements among these children are higher.

▸ The use of anonymised educational national data provides good coverage of the population and a robust middle childhood outcome.

What is already known on this topic?

▸ Antibiotics given to women with preterm rupture of membranes and no overt infection have neonatal benefit and appear safe in terms of childhood outcomes at 7 years of age.

▸ In contrast, when administered to women with spontaneous preterm labour with intact membranes there is no neonatal benefit and evidence of poorer outcomes in terms of neurodevelopmental impairment and cerebral palsy at 7 years of age.

▸ Previous studies are open to ascertainment bias in outcomes in middle childhood.
METHODS

The ORACLE study

The original trial recruited 4221 and 4148 women, respectively, to the SPL and PROM trials. Questionnaire-based follow-up information was obtained for 3196 (71%) and 3298 of 4358 children (75%) for SPL and PROM arms of the study, respectively. Mean gestational age at birth was 38 and 34 weeks, respectively, for SPL and PROM arms of the study. Overall, 6295 of 8369 (75%) children were resident in England at the completion of the ORACLE Children Study and formed the population for this study.

Data

The Department for Education (DfE) supplied full KS2 data at 11 years of age anonymously for ORACLE children categorised by treatment group. Linkage was performed by the DfE, and based on information we held on individual children. Matching was carried out probabilistically based on forename, surname, date of birth and postcode. No further information on those not matched is available because of data anonymity requirements. The KS2 data supplied comprised continuous scores for English, mathematics and science and a DfE measure of educational progress entitled contextual value added (CVA). CVA measures the progress made by pupils from the end of KS1 to the end of KS2, adjusting for external factors, such as the child’s sex, changing school and levels of deprivation, that impact pupil results at school. For further information on the derivation of this measure, see http://www.education.gov.uk/schools/performance/archive/schools_10/cvacalc.pdf (accessed 30 March 2016). In addition, the data set included the following data: age at the beginning of the KS2 assessment year, ethnicity of the child, English as first language (yes/no), free school meal eligibility (yes/no), child’s sex, Income Deprivation Affecting Children Index (IDACI) score, school type (community, voluntary/faith, foundation, other) and academic year of KS2 assessment, in addition to ORACLE group allocation information.

The DfE Research Unit was sent a computer file of study members’ records in four groups (according to their treatment allocation), and data were returned with identifiers removed (i.e., anonymised) separately for each of the four treatment groups. Identifiers comprised either the name, date of birth and postcode for each child or the Unique Pupil Identifier (UPI) for linking to KS2 outcomes; individual identifiers were then removed (leaving only the trial allocation) on the file when returned to the authors. As this was an anonymised analysis, no research ethics committee permission was required. Permission was obtained from the DfE Research Unit to use these data.

Statistical analysis

KS2 data were dichotomised into level 4 or above (considered to be appropriate progress at school) and below level 4, and Mantel–Haenszel ORs were calculated comparing erythromycin

<table>
<thead>
<tr>
<th>Table 1 Summary statistics for contextual value added score and raw scores for English, maths and science by ORACLE treatment groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preterm rupture of membranes</strong></td>
</tr>
<tr>
<td><strong>Erythromycin</strong></td>
</tr>
<tr>
<td>English (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Mathematics (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Science (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Contextual VA (n)*</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Special needs (n)</td>
</tr>
<tr>
<td>n (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Spontaneous preterm labour</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total with data</strong></td>
</tr>
<tr>
<td>English (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Mathematics (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Science (n)</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Contextual VA (n)*</td>
</tr>
<tr>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Special needs (n)</td>
</tr>
<tr>
<td>n (%)</td>
</tr>
</tbody>
</table>

Scores are the number of marks achieved.
*Contextual value added (VA) scores are expressed as a per cent improvement compared with previous assessments; for further definitions, see http://www.education.gov.uk/schools/performance/archive/schools_10/cvacalc.pdf (accessed 30 March 2016).
†Special need categories: school action, school action plus (for 2004–2006 also includes educational statements and statutory assessment); for definitions, see https://www.gov.uk/children-with-special-educational-needs/support-before-september-2014; accessed 30 March 2016.
and co-amoxiclav separately for effects on the odds of achieving less than a level 4 at KS2.

Log-linear models including covariates for erythromycin and co-amoxiclav were fitted for the aggregate KS2 levels (<2, 2, 3, 4, 5 and 6) for English, mathematics and science. Linear regression models were fitted for the raw scores for each of the three KS2 subjects. All models are adjusted for a selection of covariates. Covariates considered for inclusion within log-linear and linear regression models in addition to the antibiotic indicators were: age at the beginning of the KS2 assessment year, ethnicity, English as first language, free school meal eligibility, sex, IDACI score, school type and KS2 assessment year.

Univariate analyses were performed first to determine which covariates should be considered for inclusion within the multivariate models. All models included erythromycin and co-amoxiclav terms. Covariates (including interaction terms between the two antibiotic indicators as in the original analyses) were selected through the use of likelihood ratio tests. All statistical modelling including model selection was performed for the PROM and SPL cohorts separately. Due to large numbers of missing values for some variables (see online supplementary table S2), complete case analyses and analyses which considered only variables with <10% missing data were performed (see online supplementary tables S3 and S4).

RESULTS

Within the ORACLE Study, for children who were born to women resident in England at the conclusion of the follow-up study (2007), anonymised KS2 data were available for up to 6087 of 6295 children recruited to the original trial (97%). The DfE-supplied baseline characteristics of children born to women in the SPL and PROM groups appear similar across all variables (see online supplementary table S1).

Analysis of continuous scores and antibiotic effects was carried out separately for women in PROM and SPL groups and reported in their four factorial groups (table 1). Attainment scores in English, maths and science were similar for those who received erythromycin or not, and for those who received co-amoxiclav or not; scores between the four groups did not vary, with similar IQRs for each. The CVA score showed evidence of a small positive improvement in performance across KS1 to KS2, which did not vary by antibiotic group for either PROM or SPL. Special needs were identified in similar proportions in each group/condition ranging from 31.6% to 34.4%.

Attainment of KS2 level 4 is considered appropriate progress within this assessment paradigm; we dichotomised KS2 results and present them for PROM and SPL populations (table 2). ORs for each subject did not vary significantly by antibiotic group in either population. We then derived a log-linear model for aggregated KS2 levels adjusted for baseline data, including only variables with <10% missing data, shown in table 3. Again no effect of antibiotic or maternal trial population was observed. Finally, we performed a linear regression using the crude KS2 scores, adjusting as before, and found no significant variation of effect size by antibiotic or trial group (table 4).

DISCUSSION

Educational attainment is a good marker for cognitive outcome within perinatal cohorts, and the prevalence of special needs is closely related to gestational age at birth. We have used the results of a national, independently administered and scored...
educational test battery to evaluate outcome for children of
women recruited to the ORACLE studies.6 7 No effect of trial
intervention has been demonstrated on continuous outcome
measures, a measure of education progress (CVA measure), or on
criterion-referenced attainment or on identified special needs.
Adjusted models yield very similar results to the unadjusted ana-
lyses here, although it should be noted that adjustment for
factors postrandomisation in principle runs the risk of over
adjustment. The data show similarities to national data—in
2010, 80% of children in England at KS2 achieved level 4 or
better (the national ‘floor’ for test results) in English and 79%
in mathematics (DfE School performance tables (see http://www.
education.gov.uk; accessed 31 July 2014)). In ORACLE, respect-
ive figures were 75% and 74%. Nationally, 19% of 11-year-old
pupils have special needs, compared with 31–34% across all
study groups. It should be remembered that a high proportion
of the ORACLE trial participants gave birth prematurely (36% in
SPL and 85% in PROM groups, respectively) and one would
expect lower attainment and higher rates of special needs in
ex-preterm children.

The strength of using national data lies in their independent
ascertainment, coverage and low dropout rate (4% of children).
The tests may vary slightly from year to year, but they are con-
tinually restandardised between years to produce consistent
outcome data. The advantage of near complete coverage from
this source, as against 71–75% from parent-based follow-up in
the original ORACLE Children Study,1 2 is in the avoidance of
ascertainment bias.

Within a trial of antenatal interventions aimed at improving
neonatal and childhood condition, national educational data
provide a sensitive and robust measure of outcome. However, the
limitation of using anonymised data lies in our inability to associ-
ate data from education with our research database without indi-
vidual parental permission; hence, the effect of linkage
information and missing data (which for some results means we
only have information on half of the cohort, eg, in Science), and
thus the degree of bias contributed thereby, cannot be ascer-
tained, more granular evaluation of the effects of the two antibio-
tics in the two trial groups is not possible, and the influence on
educational attainment of other perinatal events or disability
ratings from the main study cannot be determined. Furthermore,
current data protection strategies on the part of the DfE and
the researchers may make a study such as this difficult in the future
by insisting on individual participant permissions.

Within the original ORACLE Children Study reports, we
raised concern about a small but significant increase in the risk
of cerebral palsy, following antibiotic prescription in spontane-
ous preterm labour. Subsequently, the use of macrolide antibio-
tics in term pregnancy has been associated with the occurrence
of cerebral palsy using the Health Improvement Network
(adjusted HR: 1.78, 95% CI 1.18 to 2.69),8 which appears to
confirm our concerns. Cerebral palsy is a rare outcome in the
population, and within the ORACLE studies, it comprises <3%
of the population.9 Cerebral palsy may be associated with learn-
ging problems but for children in this study the functional motor
deficit associated with cerebral palsy on the ORACLE Children

### Table 3 Erythromycin and co-amoxiclav HRs (95% CI) from the adjusted log-linear models for aggregate KS2 levels*

<table>
<thead>
<tr>
<th></th>
<th>PROM</th>
<th></th>
<th>SPL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Erythromycin</td>
<td>Co-amoxiclav</td>
<td>Erythromycin</td>
</tr>
<tr>
<td>English</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>1.00 (0.96 to 1.05)</td>
<td>1.03 (0.99 to 1.08)</td>
<td>0.97 (0.92 to 1.03)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>1.00 (0.96 to 1.03)</td>
<td>1.02 (0.98 to 1.06)</td>
<td>0.98 (0.95 to 1.02)</td>
</tr>
<tr>
<td>Mathematics</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>0.98 (0.94 to 1.03)</td>
<td>1.02 (0.97 to 1.07)</td>
<td>0.99 (0.95 to 1.03)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>0.98 (0.95 to 1.02)</td>
<td>1.00 (0.96 to 1.04)</td>
<td>0.99 (0.95 to 1.02)</td>
</tr>
<tr>
<td>Science</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>1.00 (0.95 to 1.05)</td>
<td>1.02 (0.97 to 1.07)</td>
<td>0.98 (0.93 to 1.04)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>1.00 (0.95 to 1.04)</td>
<td>1.01 (0.97 to 1.06)</td>
<td>0.99 (0.94 to 1.04)</td>
</tr>
</tbody>
</table>

*See supplemental table 2 for details of covariates used (with <10% missing data).
<10%, <10% missing data; CC, complete case analysis; KS2, Key Stage 2; PROM, preterm rupture of membranes; SPL, spontaneous labour with intact membranes.

### Table 4 Erythromycin and co-amoxiclav estimates (95% CI) from the adjusted linear regression models for raw KS2 scores*

<table>
<thead>
<tr>
<th></th>
<th>PROM</th>
<th></th>
<th>SPL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Erythromycin</td>
<td>Co-amoxiclav</td>
<td>Erythromycin</td>
</tr>
<tr>
<td>English</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>−0.54 (−2.05 to 0.97)</td>
<td>1.03 (−0.48 to 2.54)</td>
<td>0.18 (−1.46 to 1.82)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>−1.05 (−2.29 to 0.19)</td>
<td>−0.71 (−0.54 to 1.95)</td>
<td>−0.42 (−1.61 to 0.77)</td>
</tr>
<tr>
<td>Mathematics</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>−1.10 (−3.18 to 0.97)</td>
<td>0.82 (−1.26 to 2.89)</td>
<td>0.18 (−2.07 to 2.42)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>−0.74 (−2.40 to 0.92)</td>
<td>0.09 (−1.57 to 1.74)</td>
<td>−0.07 (−1.67 to 1.54)</td>
</tr>
<tr>
<td>Science</td>
<td>CC</td>
<td>&lt;10%</td>
<td>CC</td>
</tr>
<tr>
<td>CC</td>
<td>0.17 (−1.34 to 1.67)</td>
<td>1.64 (0.14 to 3.15)</td>
<td>1.47 (−0.40 to 3.34)</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>−0.07 (−1.34 to 1.19)</td>
<td>0.94 (−0.33 to 2.20)</td>
<td>0.37 (−0.91 to 1.65)</td>
</tr>
</tbody>
</table>

*See supplemental table 3 for details of covariates used (with <10% missing data).
<10%, <10% missing data; CC, complete case analysis; KS2, Key Stage 2; PROM, preterm rupture of membranes; SPL, spontaneous labour with intact membranes.
Study tended to be less severe, and anticipated effects on academic attainment would also be less severe. Furthermore, the later the age at follow-up will allow the effect of social and environmental influences to dilute the important neonatal influences. For example, despite the success of neonatal caffeine in improving neonatal and outcomes in the second year, including cerebral palsy rates, re-evaluation of the population at 5 years failed to demonstrate continuing benefit. Such findings provide reassurance of longer term safety but do not diminish identified short-term influences. Thus, any effect on educational scores from this excess would be overwhelmed by the results of the remainder of the population without cerebral palsy, but it is reassuring to see no evidence of poorer educational attainment overall.

The ORACLE study has demonstrated short-term neonatal benefit from the use of antibiotics for women with preterm rupture of the membranes and suggested longer term harm from giving women antibiotics in the presence of SPL. The follow-up of those children at 7 years of age whose mothers had SPL suggested that the prescription of erythromycin (with or without co-amoxiclav) was associated with an increase in the proportions of children with any level of functional impairment and cerebral palsy. This paper provides reassurance from the use of standardised national attainment tests and special needs for 6087 children resident in England that no benefit or harm was demonstrated on overall educational attainment for these children at 11 years.

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Contributors NM, AS and SK conceived the idea, HB carried out the analysis under the supervision of DJ and NM wrote the initial draft of the paper. All authors contributed to the design of the study, interpretation of the results and revisions of the draft.

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Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Data are available after discussion with the Oracle Study Investigators in accordance with our data-sharing policy.

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