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Ionising radiation: are orthopaedic surgeons' offspring at risk?

H G Zadeh FRCS
Specialist Registrar Grade in Orthopaedics

T W R Briggs MCh FRCS
Consultant Orthopaedic Surgeon

Department of Orthopaedics, The Royal National Orthopaedic Hospital Trust, Stanmore, Middlesex

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The hazards of exposure to ionising radiation are well documented. Fears have been raised that occupational exposure to ionising radiation by orthopaedic surgeons may have detrimental effects on the future health of their unborn offspring.

The current members of the British Orthopaedic Trainees' Association and orthopaedic consultants appointed during the last 5 years in the United Kingdom were contacted using a postal questionnaire. Obstetricians and gynaecologists of a similar age group were also contacted to act as the control group. The collected data were compared with the latest national data as published by the Office of Population Censuses and Surveys for England and Wales (OPCS, 1991).

In all, 504 questionnaires were posted to orthopaedic surgeons and 1597 to obstetricians and gynaecologists. Reply rates were 334 (66%) and 986 (62%), respectively.

Our data reveal a higher rate of congenital abnormalities as compared with the normal population in both groups ($P < 0.001$). However, there were no statistically significant differences in the rate of congenital abnormalities between the offspring of orthopaedic surgeons and obstetricians and gynaecologists ($P = 0.78$). These findings suggest that the increased rate of congenital abnormalities observed in both groups is more likely to be associated with factors other than exposure to X-rays.

In this study, male surgeons had a higher incidence of female children compared with the normal population ($P = 0.01$). The incidence of childhood malignancies does not appear to be raised in either group.

These findings suggest that the current levels of occupational exposure to X-rays by orthopaedic surgeons is unlikely to be associated with an increased risk of congenital abnormalities or childhood malignancies in their children.

Correspondence to: Mr H G Zadeh FRCS, c/o Mr T W R Briggs MCh FRCS, Consultant Orthopaedic Surgeon, The Royal National Orthopaedic Hospital Trust, Stanmore, Middlesex HA7 4LP

It is generally accepted that exposure to ionising radiation can result in genetic damage and this may become manifest in the form of congenital abnormalities or childhood malignancies in the next generation *(1)*. The use of X-ray imaging is an integral part of orthopaedic and trauma surgery. A number of recent studies have assessed the level of exposure to ionising radiation by various health workers *(1–6)*. The results have generally been reassuring, as it is reported that the level of occupational exposure to X-rays during diagnostic imaging is within the recommended limits set by the International Commission on Radiological Protection *(7)*. However, there is little data available regarding the health of the children in these groups.

Following reports from Sellafield and Hanford nuclear reprocessing plants which assert a significant association between the paternal occupational exposure to ionising radiation and an increased incidence of leukaemias or congenital abnormalities in their children *(8,9)*, fears have been raised that the children of orthopaedic surgeons may also be at risk.

The aims of this study were to ascertain the incidence of congenital abnormalities and childhood malignancies in a group of orthopaedic surgeons, comparing these findings with the normal population and a control group of surgeons who do not routinely use X-ray imaging (obstetricians and gynaecologists).

Materials and methods

The current members of the British Orthopaedic Trainees' Association and the orthopaedic consultants appointed in the last 5 years in the United Kingdom were contacted using a postal questionnaire. A similar questionnaire was sent to age matched obstetricians and gynaecologists. The former group was selected as they were more likely to be involved with operative procedures requiring long exposure time for X-rays, eg intramedullary nailing *(5)*. The latter group was selected as the control group because although they were exposed to operating theatre environment, they are less likely to have regular occupational exposure to X-rays.

Questionnaires were posted to 504 orthopaedic surgeons and to 1597 obstetricians and gynaecologists. Reply rates were 334 (66%) and 986 (62%), respectively. Data collected relating to the children of the respondents were compared with the latest national data as published by the Office of Population Censuses and Surveys for England and Wales (OPCS, 1991) *(10)*. Congenital abnormalities reported were classified according to the International Classification of Diseases, 9th Revision (ICD-9) *(11)*. Minor congenital abnormalities (as listed in OPCS, 1991) were excluded from statistical analysis. The χ^2 test with Yates' correction was used for statistical analysis.

Because of the small number of female orthopaedic surgeons with children, comparative analysis for the prevalence of congenital abnormalities between the orthopaedic surgeons and obstetricians and gynaecologists were limited to male surgeons only.

Results

From 334 orthopaedic and 986 obstetric and gynaecology respondents, 216 (65%) and 714 (72%), respectively, reported as having children. A further 9 (3%) and 17 (2%) reported having had known pregnancy events but no children. From the 216 orthopaedic surgeons with children, only 3 (1%) were female surgeons. On the other hand, a higher proportion of obstetricians and gynaecologists with children were female, ie 134 out of 714 (19%).

Table I shows the number of reported pregnancies, children, congenital abnormalities, childhood malignancies and other pregnancy events in each group. The data for obstetricians and gynaecologists were further divided into two groups according to whether they gave a history of regular exposure to X-rays, either to themselves or their spouse. Table II lists the reported congenital abnormalities for the affected children. The underlying diagnosis for the aborted pregnancies is also listed in Table II. Tables III–V summarise the results of the main statistical analysis.

Discussion

Effects of ionising radiation on the offspring

Although animal studies clearly show a causal relationship between preconception or in-utero exposure to ionising radiation and a higher incidence of birth defects and malignancies in the next generation, the evidence in humans is not as clear-cut and at times is contradictory *(1)*. In humans the main evidence is derived from studies on the survivors of the Hiroshima and Nagasaki atomic bomb explosions, workers in the nuclear industry and the offspring of women exposed to medical irradiation.

Preconception exposure to ionising radiation

The highly publicised report from the Sellafield nuclear reprocessing plant in the UK demonstrated a significant association between the level of paternal exposure to ionising radiation and increased incidence of leukaemia in their offspring *(8)*. A similar study from the Hanford Site nuclear reprocessing plant in the USA revealed an

Table I. Reported pregnancies, children, congenital abnormalities, childhood malignancies and other pregnancy events

	Orthopaedic surgeons			*Obstetricians and gynaecologists*				
				No routine X-ray exposure		*Routine X-ray exposure*		
	Male surgeons	*Female surgeons*	*Total*	*Male surgeons*	*Female surgeons*	*Male surgeons*	*Female surgeons*	*Total*
Number of surgeons with children	213	3	216	407	173	76	58	714
Pregnancies	492	9	501	1087	396	215	137	1835
Children	446	5	451	922	335	177	115	1549
Male children	210	2	212	445	174	87	57	763
Female children	236	3	239	478	161	90	58	787
Congenital abnormalities	12	1	13	21	7	5	1	34
Childhood malignancies	1	0	1	0	0	0	0	0
Children with inherited disorders	2	0	2	1	0	0	0	1
Termination for known disorders	4	0	4	6	3	2	0	11
Mid-term pregnancies	10	2	12	7	3	4	1	15
Miscarriages	32	2	34	148	52	32	21	253
Ectopics	0	0	0	2	2	1	0	5
Stillbirths	0	0	0	2	0	0	0	2

Table II. Reported abnormalities

Congenital abnormalities included in the analysis	*ICD-9 classification*	*No. of cases orthopaedic surgeons*	*No. of cases obstetricians & gynaecologists*
Retinitis pigmentosa	362.7	0	1
Congenital squint	379.5	0	2
Congenital deafness and retinitis pigmentosa	389.0 & 362.7	0	1
Hydrocephalus and spina bifida	741.0	0	1
Spina bifida	741.9	0	1
Charge's syndrome	744.0 & 748.3	0	1
Absent pinna, middle ear and microtia	744.2	0	1
Ventricular septal defect	745.4	1	6
Atrial septal defect	745.5	0	1
Congenital heart disease (unspecified)	746.9	0	3
Cleft palate	749.0	0	1
Cleft lip	749.1	1	0
Cleft lip and palate	749.2	0	1
Tongue tie and bifid tongue	750.0	1	1
Hypospadias (major) and pyloric stenosis	752.6 & 750.5	0	1
Renal agenesis	753.0	0	1
Beckwith's syndrome	753.1	0	1
PUJ obstruction	753.2	0	1
CDH/DDH	754.3	3	2
CDH and hypospadias	754.3 & 752.6	0	1
Genu recurvatum	754.4	0	1
Polydactyly	755.0	2	3
Syndactyly (toes)	755.1	0	1
Fibular hemimelia	755.3	1	0
Cranial synostosis	756.0	1	0
Hemivertebra	756.1	0	1
Achondroplasia	756.4	1	0
Giant hairy naevus	757.3	1	0
Chromosomal abnormality (unspecified)	758.5	0	1
Vater's syndrome	759.7	1	0
Short umbilical cord	762.6	0	1
Termination of pregnancy for known congenital abnormalities			
Hydatiform mole	236.1	0	1
Cystic fibrosis	277.0	1	0
Metachromatic leukodystrophy	330.0	1	0
Rubella	655.4	0	1
Anencephalus	740.0	0	2
Spina bifida	741.9	0	2
Tricuspid atresia	746.1	1	0
Renal abnormality, oligohydramnios	753.0	0	0
Down's syndrome	758.0	0	2
Edwards' syndrome	758.2	0	1
Hydrops	773.3	1	1

Table III. Congenital abnormality rates and sex ratios

	Congenital abnormality rates per 10 000 live/stillbirths	*Sex ratio male/female*
Population (OPCS 1991) *(10)*	101.5	51%/49%
Orthopaedic surgeons	288.2	47%/53%
Obstetricians and gynaecologists	232.4	49%/51%
Orthopaedic surgeons (corrected) †	190.9	—
Obstetricians and gynaecologists (corrected) †	143.5	—
Male orthopaedic surgeons	269.0	47%/53%
Male obstetricians and gynaecologists	236.6	48%/52%
Female obstetricians and gynaecologists	222.2	51%/49%

† Corrected for the total number of children assuming there were no further congenital abnormalities in the children of non-responders

Table IV. Comparative analysis for congenital abnormalities

Comparative analysis for congenital abnormalities	χ^2	*P*
Population *vs* orthopaedic surgeons	13.82	0.0002
Population *vs* orthopaedic surgeons (corrected) †	4.55	0.033
Population *vs* obstetricians and gynaecologists	25.00	0.0000006
Population *vs* obstetricians and gynaecologists (corrected) †	3.97	0.046
Male orthopaedic surgeons *vs* male obstetricians and gynaecologists with no history of radiation exposure	0.08	0.78
Male obstetricians and gynaecologists *vs* female obstetricians and gynaecologists	0.09	0.76
Obstetricians and gynaecologists with no history of radiation exposure *vs* obstetricians and gynaecologists with history of radiation exposure	0.00	0.99

† Corrected for the total number of children assuming there were no further congenital abnormalities in the children of non-responders

Table V. Comparative analysis for sex ratio of children

Comparative analysis for sex ratio of the children	χ^2	*P*
Population *vs* male orthopaedic surgeons	2.96	0.13
Population *vs* male obstetricians and gynaecologists	3.56	0.04
Population *vs* male surgeons (both groups included)	6.36	0.01
Population *vs* female surgeons (both groups included)	0.00	0.98
Male orthopaedic surgeons *vs* male obstetricians and gynaecologists with no history of radiation exposure	0.12	0.73

association with congenital abnormalities, especially neural tube defects *(9)*. In contrast, the study from the Dounreay nuclear reprocessing plant in the UK did not find a similar association *(12)*.

An increase in the rate of various malignancies has been reported in the children of the women who received medical irradiation before conception *(13,14)*. Down's syndrome has also been linked with preconception exposure to ionising radiation by a number of studies *(1)*. However, no similar findings were observed in the children of the survivors of the atomic bomb explosions *(15)*.

Intrauterine exposure to ionising radiation

An increased rate of neurological injury, mental retardation, microcephaly has been demonstrated in the children of the survivors of atomic bomb explosions. The occurrence and severity of these effects appear to be dose dependent and more severe if the exposure was during the gestational period of 8–15 weeks *(16)*. The incidence of various types of malignancies is also reported to be elevated in the same group *(17,18)*. Exposure to diagnostic X-ray imaging during pregnancy has been linked to a higher rate of childhood malignancies in a number of studies *(13,14)*.

Exposure to operating theatre environment

Adverse pregnancy outcomes in staff working in an operating theatre environment has been reported in numerous studies *(19–26)*. Exposed female anaesthetic, nursing and other paramedical staff appear to suffer a higher incidence of miscarriages, stillbirths and congenital abnormalities compared with other staff who were not exposed to the operating theatre environment.

The evidence is less clear-cut in male staff. The incidence of miscarriages and stillbirths in the spouse of exposed male staff does not appear to be significantly raised compared with non-exposed control groups. In two of the largest studies, male anaesthetists reported a higher incidence of congenital abnormalities in their offspring compared with doctors in other specialties who did not work in operating theatres *(20,21)*.

Although not proven conclusively in humans, these effects are generally believed to be caused by occupational exposure to inhalational anaesthetic agents *(27)*. Teratogenic and carcinogenic properties of the inhalational anaesthetic gases such as halothane and nitrous oxide have been reported in animal experiments *(27)*. Consequently, it has recently become routine practice to reduce unwanted leakage of anaesthetic gases into the operating theatre environment.

Children of the orthopaedic surgeons and obstetricians and gynaecologists

The increased rate of congenital abnormalities observed in our study in both groups is a cause for concern. However, as there were no statistically significant differences in the rate of congenital abnormalities between the offspring of orthopaedic surgeons and obstetricians and gynaecologists, these findings suggest that the increased rate of congenital abnormalities observed in both groups is more likely to be associated with factors other than exposure to X-rays. This finding correlates well with the data published by the International Commission on Radiological Protection, which puts the risk of severe hereditary effects for adult workers as 0.008 per Sievert of whole body radiation exposure *(7)*. The studies looking at the level of occupational radiation exposure by orthopaedic surgeons, have demonstrated that the level of radiation exposure to the trunk of the surgeon, which is normally shielded with a lead apron, were negligible *(3,6)*.

In keeping with other previously published studies, occupational exposure to operating theatre environment may be the main aetiological cause for the raised incidence of congenital abnormalities observed in the children of both orthopaedic surgeons and obstetricians and gynaecologists. However, our results should be interpreted with caution. Firstly, medical personnel will certainly be more thorough with the reporting of congenital abnormalities in their children and although the national data for incidence of congenital abnormalities is generally believed to be accurate, underreporting may occur, especially if the congenital abnormalities are recognised late *(10)*. Secondly, the relatively low reply rates in this survey may introduce further bias. Surgeons who have children with congenital abnormalities are probably more likely to reply to this type of study and therefore a greater proportion of non-responders may have normal children. However, even accounting for the children of the remaining orthopaedic surgeons and obstetricians and gynaecologists who did not reply to our questionnaire and assuming that none had any affected children, the raised prevalence of congenital abnormalities still remains statistically significant when compared with the normal population ($P=0.033$ and 0.046, respectively).

It is reassuring that there were no reported cases of childhood leukaemias. The only reported case of childhood malignancy was a single case of an adrenal neuroblastoma. This tumour is not believed to be associated with exposure to ionising radiation *(28)*.

The maternal age at birth has been shown to influence the rate of congenital abnormalities *(10)*. According to national data, the age group 30–34 years has the lowest rate of congenital abnormalities and the rate rises for both younger and older age groups, especially for those over the age of 45 years (Table VI). Figure 1 shows the distribution of the maternal age at birth for the orthopaedic surgeons, obstetricians and gynaecologists and the normal population. There is a higher proportion of younger mothers in the normal population compared with both the orthopaedic surgeons and obstetricians and gynaecologists. However, in the case of both the orthopaedic surgeons and obstetricians and gynaecologists, the majority of the children were born at the maternal age groups associated with the lowest expected rates of congenital abnormalities, ie 25–29 and 30–34 years (Fig. 1). When standardised according to the various age groups, the expected rate of congenital abnormalities for the children of orthopaedic surgeons and obstetricians and gynaecologists were 97.0 and 98.1 per 10 000 total births, respectively. With the national rate being 101.5 per 10 000 total births, this means that the expected rate of congenital abnormalities for both orthopaedic surgeons and obstetricians and gynaecologists should be lower than the normal population. The opposite was actually observed in this study.

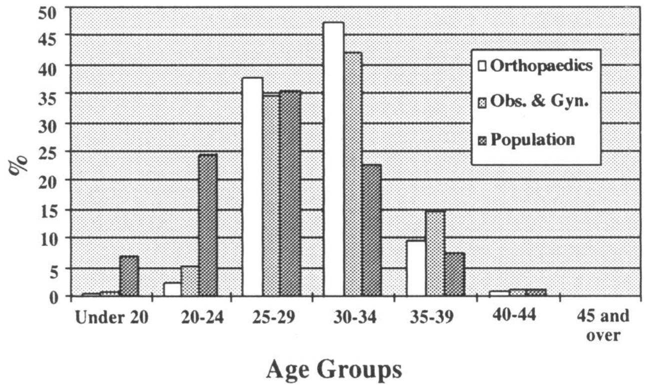

Figure 1. Maternal age at birth for orthopaedic surgeons, obstetricians and gynaecologists and UK population.

For the other main comparative groups, ie spouse of male orthopaedic surgeons and male obstetricians and gynaecologists with no history of radiation exposure, the expected rate of congenital abnormalities after standardising for the maternal age groups were 97.0 and 98.7 per 10 000 total births, respectively. However, this difference between the expected rate of congenital abnormalities in the above two groups, with our current sample size was unlikely to significantly bias the results. Recalculating the comparative analysis between these two groups using the Mantle–Haenzel method which accounts for the incidence of congenital abnormalities in the various maternal age groups, the difference is still statistically not significant ($0.50 > P > 0.10$).

In this study both male orthopaedic surgeons and male obstetricians and gynaecologists reported a higher incidence of female children than otherwise expected, 53% and 52%, respectively ($P=0.13$, $P=0.04$, respectively, and $P=0.01$ if both groups are combined). The national data consistently reveal a predominance of male children ~51% *(10)*. For female surgeons the sex ratios of their children were similar to the national statistics. The higher incidence of female children in our study is interesting as similar findings have also been documented in other health workers, notably the anaesthetists *(23,30)*. The cause of this phenomenon is not well understood, but

Table VI. Congenital abnormalities rates per 10 000 total births, according to maternal age at birth for England and Wales (OPCS 1991) *(10)*

Age (years)	*Under 20*	*20–24*	*25–29*	*30–34*	*35–39*	*40–44*	*45 and over*	*Total*
Rates	112.6	103.7	94.5	93.2	118.7	141.5	209.9	101.5

the suppressive effects of inhalational anaesthetic agents on the motility of spermatozoa may be a factor *(31)*.

The incidence of miscarriages in this study is within the range reported by other series looking at the normal population *(32,33)*. There were no statistically significant differences observed in the incidence of miscarriages between obstetricians and gynaecologists with a history of radiation exposure or no history of radiation exposure ($P=0.48$), nor between the male (spouse) or female obstetricians and gynaecologists ($P=0.78$). However, there was a statistically significant difference in the incidence of miscarriages observed between orthopaedic surgeons and obstetricians and gynaecologists with no history of radiation exposure (rates 6.5% and 13.6%, respectively, $P=0.000055$). This finding may partly be explained by the fact that the latter group were probably more accurate in recognising early miscarriages, which may have otherwise been ignored as a late menstrual cycle.

We conclude that the current levels of occupational exposure to X-rays by orthopaedic surgeons is unlikely to be associated with an increased risk of congenital abnormalities or childhood malignancies in their children. The increased risk of congenital abnormalities observed in this study in the children of both orthopaedic surgeons and obstetricians and gynaecologists is a cause for concern and may be related to occupational exposure to operating theatre environment. A comprehensive national study involving all the operating theatre personnel, similar to the American study *(20)* is long overdue.

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