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Scuba diving and pregnancy: Can we determine safe limits?

M. ST LEGER DOWSE[1], A. GUNBY[1], R. MONCAD[1], C. FIFE[2], & P. BRYSON[1]

[1]*Diving Diseases Research Centre (DDRC), Hyperbaric Medical Centre, Plymouth, UK and* [2]*The University of Texas Health Science Center, Memorial Hermann Center for Hyperbaric Medicine, Houston, Texas, USA*

Summary
No human data, investigating the effects on the fetus of diving, have been published since 1989. We investigated any potential link between diving while pregnant and fetal abnormalities by evaluating field data from retrospective study No.1 (1990/2) and prospective study No.2 (1996/2000). Some 129 women reported 157 pregnancies over 1,465 dives. Latest gestational age reported while diving was 35 weeks. One respondent reported 92 dives during a single pregnancy, with two dives to 65 m in the 1st trimester. In study No.2 >90% of women ceased diving in the 1st trimester, compared with 65% in the earlier study. Overall, the women did not conduct enough dives per pregnancy, therefore no significant correlation between diving and fetal abnormalities could be established. These data indicate women are increasingly observing the diving industry recommendation and refraining from diving while pregnant. Field studies are not likely to be useful, or the way forward, for future diving and pregnancy research. Differences in placental circulation between humans and other animals limit the applicability of animal research for pregnancy and diving studies. It is unlikely that the effect of scuba diving on the unborn human fetus will be established.

Introduction

Women are increasingly seeking careers in scuba diving, but the majority of the recommendations and understanding of the safe limits to scuba dive are based on the physiology of fit young males; not on young women who may become pregnant. Diving during pregnancy will continue to occur, either due to inadvertent exposure before a woman is aware of her pregnancy, or to women choosing to continue diving despite warnings to the contrary. Information resources regarding the safety of diving and pregnancy are not easily available to the female diver or her medical advisor. Medical practitioners are not always well placed to give balanced advice to a woman who has unintentionally dived while pregnant. Additionally, the outcome of a pregnancy where the mother has presented with decompression illness (DCI) and undergone treatment in a recompression chamber is largely undocumented (Jennings 1987).

Concern surrounding diving and pregnancy has centred on the fetal susceptibility to DCI, as the fetal circulation differs from that of the adult. In the adult, almost all the output from the heart travels through the lungs where any small bubbles formed as a result of diving, are removed. The fetal circulation bypasses the lungs so that any bubble that forms is potentially harmful (Newhall 1981; Fife and Fife 1994).

Retrospective human studies have tried to determine the effects of scuba diving on the unborn child with particular emphasis on fetal abnormalities (Bangasser 1978; Bolton 1980; Betts 1985), with Bakkevig (1989) publishing the most recent retrospective human study in 1989. Overviews of the subject also exist, with some authors considering health issues other than DCI and fetal abnormalities, observing that in some women, in the 3rd trimester, seawater may gain entrance to the womb thus increasing the chances of infection and premature labour (Newhall 1981; Cresswell and St Leger Dowse 1991; Fife and Fife 1994; Camporesi 1996; Morales et al. 1999). Case notes have also been published (Turner and Unsworth 1982; Sauceda Gonzalez et al. 1995). Animal studies exist but differences in placental circulation between humans and other animals limit the applicability of the animal model for pregnancy and diving research. Results of animal studies have also been shown to be contradictory and controversial in their findings (Fife et al. 1978; Stock et al. 1980; Nemiroff et al. 1981; Gilman et al. 1982; Bolton-Klug et al. 1983; Gilman et al. 1983; Willson et al. 1983; Powell and Smith 1985). Female specific Undersea and Hyperbaric Medical Society (UHMS) Workshops: Effects of Diving on Pregnancy (UHMS 1978) and Women and Diving (UHMS 1986) attempted to generate further research, but little work has been performed since then.

We evaluated data obtained during two recent unrelated field studies in order to investigate any potential link between diving whilst pregnant and foetal abnormalities. The value of using field data in addressing this particular issue is also discussed.

Correspondence: M. St Leger Dowse, DDRC, Hyperbaric Medical Centre, Tamar Science Park, Research Way, Plymouth, Devon PL6 8BU, UK.
E-mail: marguerite@mstld.co.uk

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Methods

Data gathered during a retrospective analysis of gender differences in diving were evaluated (study No.1 in 1990/2), together with data gathered during a prospective analysis of diving and the menstrual cycle (study No.2 in 1996/2000). Although neither study was specifically designed to investigate the safe limits and outcome of diving while pregnant, both studies requested data from women who dived while pregnant. Information gathered included: gestation in weeks at first and last dive; total number of dives during pregnancy; depth ranges; number of dives requiring decompression stops; number of multi-dive days and number of consecutive days dived. Details concerning outcome (spontaneous abortion, clinical termination, still birth and live birth), method of delivery and weight of baby at birth were also requested. In addition to fixed option responses, respondents were asked to provide free text comment if they felt it appropriate. Other data included demographics and diving history. Participation was entirely voluntary in both studies, informed consent was obtained where appropriate and no incentive was offered to participate. Each woman was free to terminate her participation in the project at any time. Approval for both studies was sought and obtained from the UK sports diving medical committee – ethical approval was not considered appropriate. Trained operators entered all data and quality assessment was implemented as appropriate. Statistical analyses were not considered appropriate in the presentation of these data.

Results

Scrutiny of both studies showed 129 women had dived while pregnant, reporting 1,465 dives during 157 pregnancies. The age range of the women from both studies, at the time of the first dived pregnancy was 34 (mean of 30 with standard error 0.4).

More than 50% of the diving took place in less than 15 m. In the earlier study (No.1) the deepest dive reported was 65 m, with the same respondent reporting 92 dives during a single pregnancy (including two dives to 65 m in the 1st trimester). In the later study (No.2) 25 m was the deepest dive reported from 72 dives during pregnancy by a single respondent.

In study No.1, 65% of women ceased diving in the first trimester, with respondents reporting 12 pregnancies where the first dive had been made in the 2nd trimester; and one woman making her first dive during pregnancy in the 3rd trimester at 35 weeks. By comparison, in study No.2, more than 90% of women ceased diving in the first trimester, with 26 weeks reported as the latest gestational age of diving. In the much earlier Bolton study (1980) 20% of women were still diving in the 3rd trimester (Figure 1).

A total of 25% of the 157 pregnancies failed: one stillbirth, 16 terminations and 22 spontaneous abortions. Apart from three ectopic pregnancies, the majority of the terminations were for social reasons, with the exception of two in the earlier study (No.1), where an influential factor had been the unknown effects of diving on pregnancy. The spontaneous abortion rate in this combined study group of diving women was no different than the rate in the general UK population (Stirrat 1990a,b).

Of the 118 live births, 80% were perceived by the respondents as problem free, with the remaining 20% of women reporting a variety of perceived problems with the pregnancy or outcome, ranging from 'spotting up to 26 weeks' to low birth weight.

Overall, women did not conduct enough dives per pregnancy to apply statistical models regarding any effect of diving on the fetus. Free form comments revealed a number of women were participating in other risk activities that may affect the well-being of the unborn fetus. We present some of this unsolicited free format response as a point of interest in Table I.

Discussion

The findings from this study, spanning 10 years from the start of study No.1 to the end of study No.2, suggested that fewer women were diving while pregnant than in the past; thus the recommendation (do not dive while pregnant) given by the diving training organisations is being heeded by female recreational divers. This study, illustrated by some of the case histories in free form text, also demonstrated the complex underlying factors that exist with regard to the lifestyles and activities of a typical female recreational diver. In the past, it has been debated that there may be a relationship between fetal abnormalities and deep diving (Bolton 1980; Betts 1985; Bakkevig et al. 1989). However, in our data there was no apparent association between deep dives and fetal abnormalities, and many women in this study were diving across all categories of depths and reported no problems with the pregnancy or the outcome.

There are several possible mechanisms by which inert gas could affect the fetus. The fetal on and off gassing of nitrogen via the placenta has not been characterised in order to class it as a fast or slow 'tissue' in terms of gas dynamics. There could be arguments both ways that gas exchange is fast due to the high volume of blood flow through the placenta or that gas exchange is slow, as this has to occur by diffusion through the microvilli. There are no data available regarding human fetal gas kinetics. It is now relatively well accepted that in adult humans, gas can form within the tissue itself, called autochthonous bubble formation (Francis and Mitchell 2003). This mechanism may account for some forms of neurological decompression sickness affecting the brain or spinal cord. There is no reason to believe that gas bubbles cannot form within human fetal tissues given the right circumstances. In adult humans, the lungs usually filter the bubbles that evolve in the venous circulation. However, the fetal lungs are by-passed via the patent foramen ovale and the patent ductus arteriosus. Thus, any venous bubbles would be directly arterialised in the fetal circulation, becoming arterial gas emboli that could then lodge in formative organs. Although the fetal lungs are not available to act as bubble filters, it is possible that the liver could act in a similar role as liver filtration of bubbles has been shown in adults after a deep dive, and this might act as a 'safety valve' for the fetus (Butler et al. 1995).

A detailed discussion of the potential effects of diving on the fetus is beyond the scope of this paper, but previous articles have failed to offer a logical approach as to what sort of problems might be caused by decompression generated bubbles, given the timing of diving in relation to gestational age. For example, there is no evidence to believe that diving can cause heritable chromosomal anomalies, regardless of the point in gestation at which

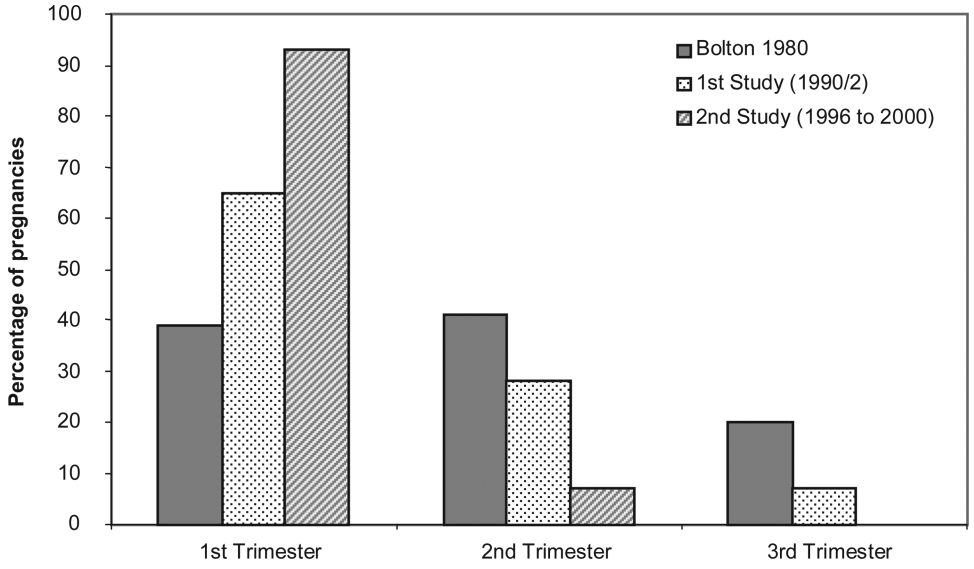

Figure 1. Latest time of diving while pregnant.

Table I. Case notes

Case 1
Neonatal death 18 h after delivery. The baby was diagnosed as suffering from 'severe diaphragmatic hernia'. The respondent reported 10 dives in total: one >20 m, the last dive being in week 21. She also consumed alcohol during the pregnancy.

Case 2
Reported that her baby was born with an extra digit on the left hand. It was successfully tied off. She reported 13 dives: four in the 15–20 m range between weeks 20 and 33. She consumed the occasional glass of wine with a meal while pregnant.

Case 3
Reported that she felt extremely ill during diving. After continuing to feel unwell during the pregnancy, it was decided to terminate the pregnancy at 18 weeks. It was found that although the placenta appeared to indicate a pregnancy of 18 weeks, the fetus showed a size of 8–10 weeks. The respondent was also a skydiver and in the first 6 weeks of pregnancy had been to an altitude of 10,000 feet at least six times. She had dived to no more than 10–12 m. She reported smoking cigarettes during pregnancy.

Case 4
Reported that her baby had a seizure at 3 days old; a blood infection was suspected. The baby was full term and weighed 10 lb 10 oz. She reported eight dives, two >20 m in the first trimester. She drank alcohol, 1 unit a day in the 1st trimester and thereafter, 3 units per day 4 days a week, she also admitted to 'occasional hashish' while pregnant.

Case 5
Was an active horseback rider until the 6th month of her pregnancy, when labour commenced at 33 weeks; the baby weighing 3 lb 4 oz. Her 10 dives took place in the 15–20 m range up to week 20. It was concluded that the placenta had torn away, resulting in premature labour, following a fall from a horse. She did not drink alcohol or smoke during pregnancy.

diving occurs. Furthermore, the fetal heart does not begin to beat until week 3, so gas bubbles cannot be distributed via the fetal circulation until it exists. Major organ development begins about week 8, although the early brain has already begun to form. One could postulate that gas emboli to one of these developing organs might be catastrophic and cause agenesis or significant malformation. It seems likely that in the early stages of development, significant gas bubble disease might be likely to cause fetal demise rather than injury. By week 12, the placenta is well established and the embryonic stage is completed, so it is unlikely that gas bubble disease could cause agenesis of an organ after this point in gestation. It is not known whether decompression generated bubbles could have a negative effect on the placenta. One might postulate that after week 14, manifestations of fetal decompression sickness could include neurological problems such as spinal cord injury, but no such problems have ever been reported.

In recent years, there has been a dearth of human data from which to debate any safe limits for scuba diving while pregnant. What seems apparent is that despite the theoretical risk of diving during pregnancy many women who dive while pregnant do so without any complications. Of the women who report pregnancy-related problems, none can be clearly related to diving and most are unlikely to be related to diving.

This study allowed scrutiny of the largest number of dived pregnancies recorded to date. In both parts of the study (retrospective and prospective) women were not focused into the subject of diving and pregnancy, therefore reducing the likelihood that only women experiencing problems with a dived pregnancy would be likely to respond. Diving histories and demographics, collected in both parts of the study, allowed more comprehensive background data to be observed than in previous studies. The retrospective study was anonymous and resulted in a number of respondents reporting information, such as recreational drug use, that may not have been otherwise reported.

This study demonstrated there are underlying variables in data of this type likely to influence the findings. For example, some women in our study were participating in other risk sports such as skydiving and horse riding, as well as indulging in social risks like recreational drug use. Many continued to consume alcohol throughout pregnancy. Limiting factors of this study were the lack of a control group and access to obstetric records due to the anonymity

of the earlier retrospective study, thus there was no ability to follow-up respondents.

Previous retrospective human studies have attempted to assess the risk to the fetus due to diving while pregnant. Bangasser (1978) found no abnormalities in babies born to 72 mothers who had dived while pregnant. Bolton (1980) interestingly concluded from 136 women who had dived during pregnancy that there was a significantly higher risk of the incidence of birth defects when compared with the 'did not dive while pregnant' group in her study. However, the incidence of birth defects in the diving group was within the national range and did not differ significantly from the national trends for birth defects of the USA. Two further studies (Betts 1985; Bakkevig et al. 1989) with 76 and 34 dived pregnancies, respectively, both observed an incidence of fetal abnormalities in the reported dived pregnancies. The number of respondents in both surveys was too small to be statistically significant or meaningful, but both authors recommended that if a woman dived while pregnant, she should limit her diving to shallow depths, 20 m and 10 m, respectively. These depth limit recommendations were based on the possibility that high nitrogen or oxygen partial pressures, or super-saturation following decompression may harm the fetus. Three studies were diving and pregnancy specific and therefore likely to attract responses from women with a problem to report (Bolton 1980; Betts 1985; Bakkevig et al. 1989).

The study performed by Bolton (1980) has long been regarded as the major work in the field. There were three aspects to the study: (1) to determine the similarities and differences between those women who dived while pregnant, and those who dived prior to but not during pregnancy; (2) to investigate the extent and type of diving during pregnancy; (3) to observe obstetric and fetal outcome. It was on this later objective that the main focus of the findings dwelt. However, the maternal age of the women was not known, and neither was the week of gestation of the first and last dive while pregnant; the time factors instead being limited to a less precise definition of 'months'. Additionally, although there were 139 women who had dived at some time during one or more pregnancies, only the last dived pregnancy was included for analysis of fetal and obstetric outcome.

With complex demographic issues likely to affect outcome, it is imperative that any future study takes these factors into account. However, bearing in mind the current recommendation not to dive while pregnant, we now face the following conundrum: the distribution of information, regarding the possible hazards of diving while pregnant, has reduced the population for study below that needed to answer the question. In order to detect a 50% increase in the incidence of birth defects, due to diving during pregnancy, a study population of the order of 4,000 women would be required with a relevant degree of exposure to diving during gestation. This figure is based on assumptions that the baseline incidence of birth defects in the general population is 1%, and that diving would cause as much as a 50% increase in birth defect incidence. Such a study would be further complicated by the difficulties of quantifying the degree of exposure specifically to risk from diving during pregnancy. The number of dives, depth of dives, cumulative effects of multiple dives, decompression profiles and times of gestation when the dives took place are a few of the factors that would need to be taken into account. Thus future field studies seeking to determine the safe limits to dive while pregnant would be exceedingly complex.

In our earlier retrospective study, 11% of women reported having dived while pregnant. In contrast, during the time of the second study, barely 3% actually reported diving during pregnancy. This trend is illustrated in Figure 1, with the comparison between the Bolton study (1980) and the two DDRC studies (1990/2 and 1996/2000), which appears to show that women either refrain from diving as soon as pregnancy is confirmed, or stop diving much earlier in the pregnancy than female divers in the past. This suggests women are observing training recommendations and now diving less, or not at all, while pregnant.

Conclusion

It is apparent the scientific community have made no further progress since the UHMS workshops of 1978 (Effects of Diving on Pregnancy) and 1986 (Women in Diving) when it was noted that a number of areas required further, rigourous study and that all those who had the capabilities to attack the questions were encouraged to do so in the near future. Some 20 years later, the risk of diving while pregnant remains un-quantified.

The data presented in this paper indicate that women are increasingly observing the diving industry recommendation, which is to refrain from diving while pregnant. It was not possible to establish a correlation between diving and fetal abnormalities and safe limits to dive. This does not imply that diving is safe while pregnant, but neither is it possible to recommend or establish safe limits within which to dive. The way forward remains elusive with field studies unlikely to be useful for future diving and pregnancy research and animal research being of limited value due to differences in placental circulation between animal models and humans. However, available data emphasises that women who have dived while pregnant need not be encouraged to terminate their pregnancy.

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