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Original Article

Do Male Medical Doctors Who Are Exposed to Ionizing Radiation Have Less Sons?

İonize Radyasyona Maruz Kalan Erkek Doktorların Erkek Çocuk Sahibi Olma Sıklığı Daha mı Azdır?

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ABSTRACT

Objective: In this study, we aimed to compare the proportion of male babies and female babies of male physicians who are exposed and not exposed to low-dose ionizing radiation.

Methods: There were 177 male physicians involved in the study. Data were collected via telephone and one-to-one surveys. Orthopedic surgeons and gynecologists were involved in the study as surgical specialties, pediatricians were involved as a physician group, neither working in the operation room environment nor using fluoroscopy. The number of children, sons and daughters, were asked. Hours spent in the operation room were asked to surgeons. Orthopedic surgeons were asked to mention their subspecialties and the frequency of fluoroscopy use per week.

Results: Having a daughter was not significantly different among 3 physician groups ($P > .05$). But orthopedic surgeons had significantly lesser sons than obstetrics gynecology specialists and pediatricians ($P = .002$). Logistic regression analysis was performed to calculate the likelihood ratio of having a son. Being a pediatrician increased the likelihood of having a son (odds ratio: 3.813, 95% CI, 1.682-8.642, $P = .001$) when compared to orthopedic surgeons. There was no difference when pediatricians and obstetrics gynecology specialists were compared in terms of having a son (odds ratio: 0.962, 95% CI, 0.385-2.408, $P = .935$).

Frequency of fluoroscopy use and having a son was analyzed among orthopedic surgeons and more than 50 shots per week decreased the likelihood of having a son among orthopedic surgeons (odds ratio: 0.353 with 95% CI, 0.178-0703, $P = .030$).

Conclusion: Fluoroscopy could negatively affect Y-chromosome-bearing sperms, eventually resulting in orthopedic surgeons to have significantly lesser sons than obstetricians/gynecologists and pediatricians. Among orthopedic surgeons when there is an

ÖZ

Amaç: Bu çalışmada, düşük doz ionize radyasyona maruz kalan ve kalmayan erkek doktorların erkek bebek ve kız bebek sahibi olma oranlarını kıyaslamayı amaçladık.

Metod: Çalışmaya 177 erkek doktor dahil edildi. Veriler telefonla ve birebir anketler ile toplandı. Ortopedi ve Kadın-Doğum uzmanları cerrahi branşlar olarak çalışmaya dahil edilirken; pediatristler gerek ameliyathane ortamında çalışmayan gerekse skopi kullanmayan bir branş olarak dahil edildi. Çocuk sayısı, erkek ve kız çocuk sayıları kaydedildi. Cerrahlara ameliyathanede geçirdikleri süre soruldu. Ortopedistlerden uğraştıkları alt branşları ve haftalık floroskopi kullanım sürelerini belirtmeleri istendi.

Sonuçlar: 3 doktor grubu arasında kız çocuk sahibi olma sıklığında belirgin farklılık yoktu ($P > .05$). Fakat ortopedistlerin erkek çocuk sıklığı kadın-doğum uzmanları ve pediatristlerden belirgin olarak azdı ($P = .002$). Erkek çocuk sahibi olma sıklığını saptamak için lojistik regresyon analizi yapıldı. Pediadrist olmanın ortopedistlerle kıyaslandığında erkek çocuk sahibi olma oranını artırdığı saptandı (odds oranı: 3.813, 95% CI, 1.682-8.642, $P = .001$). Erkek çocuk sahibi olma sıklığı açısından kadın-doğum uzmanları ve pediatristler kıyaslandığında belirgin bir fark görülmedi (odds oranı: 0.962, 95% CI, 0.385-0.2408, $P = .935$).

Ortopedistler arasında floroskopi kullanma sıklığı ve erkek çocuk sahibi olma sıklığı incelendiğinde, haftada 50 çekimden fazla floroskopi kullanımının erkek çocuk sahibi olma sıklığını belirgin olarak azalttığı görüldü (odds oranı: 0.353, 95% CI, 0.178-0.703, $P = .030$).

Yorum: Floroskopi Y kromozomu taşıyan spermleri etkileyerek ortopedistlerin, kadın-doğum uzmanları ve pediatristlerle kıyaslandığında daha az erkek çocuk sahibi olmasına yol açabilir. Ortopedistler arasında da floroskopi kullanımı arttığında

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increase in the frequency of fluoroscopy, the likelihood of having sons significantly decreases. The gender of the baby depends on many factors; further studies with sperm analyses and genetic analyses could be done to enlighten this topic.

Keywords: Low-dose ionizing radiation, fluoroscopy, orthopedic surgeon, occupational hazard of radiation

erkek çocuk sahibi olma oranı belirgin olarak azalmaktadır. Bebeğin cinsiyeti pek çok faktöre bağlıdır; bu sebeple konunun aydınlatılması için sperm analizleri ve genetik analizlere ihtiyaç duyulmaktadır.

Anahtar kelimeler: Düşük doz ionize radyasyon, floroskopi, ortopedist, radyasyonun mesleki zararları

INTRODUCTION

Fluoroscopy is commonly used in certain medical specialties such as orthopedic surgery, neurosurgery, radiology, and cardiology.[1] The use of intraoperative C-arm fluoroscopy allows less invasive interventions and it is a useful tool which facilitates surgical procedures. Previously, numerous studies have been conducted on the negative effects of ionizing radiation, emitted by the use of fluoroscopy. These studies are mostly focused on the development of tumoral lesions originating from various tissues, especially hematologic and lymphatic systems, or negative effects seen in the reproductive organs.[2]

Ionizing radiation causes a wide spectrum of DNA damage such as damaged nucleotide bases, cross-linking, and single or double-strand breaks. These negative effects may lead to apoptosis of the cell or various mutations in the surviving cells and, furthermore, carcinogenesis may develop.[3]

Various studies reveal that ionizing radiation arising due to the use of fluoroscopy may affect not only the physician but also the babies born. It is also widely argued that some malignancies with hematologic origin or some congenital abnormalities are seen more frequently in the children of physicians, compared to the children of the general population.[4-7]

It was shown that environmental toxins such as radiation, heavy metal exposure, heat, smoking, organic solvents, and pesticides can cause gonadotoxic effects.[8] The formation of fully functional spermatozoa from spermatogonial stem cells lasts 60-70 days. Sperm-forming cells may be affected by ionizing radiation through a number of possible mechanisms, including the formation of reactive oxygen radicals, direct radiation effect, and expression of genes involved in radiation sensitivity during the differentiation process of spermatogenesis.[9] Paternal ionizing radiation exposure is proven to increase the risk of congenital abnormalities and childhood leukemias in newborn babies.[10,11]

MAIN POINTS

- Radiation impairs sperm quality and quantity at different doses; exposure to over 6000 Rad can cause permanent azoospermia and infertility, whereas low doses as 15 Rad can suppress spermatogenesis.
- Radiation exposure can negatively affect Y-chromosome-bearing sperms.
- Occupational exposure to C-arm fluoroscopy which emits low-dose ionizing radiation can have an effect on live-born baby's gender, favoring to have more girls.
- Frequency of fluoroscopy shots can have an impact on female/male babies born to exposed male physicians.

In this study, we hypothesized that low-dose ionizing radiation emitted via fluoroscopy could impair Y-chromosome-bearing sperms, leading to a decrease in the male/female embryo ratio. This study is designed among male physicians of 3 different specialties; orthopedic surgeons, obstetricians and gynecologists, and pediatricians. The primary outcome measure was to compare the proportion of male and female babies of physicians who are exposed and not exposed to radiation. The secondary outcome measure was to evaluate any relationship between the frequency of fluoroscopy use by orthopedic surgeons and any decrease in the possibility of having a male baby.

METHODS

This study was conducted between December 2019 and March 2022 in a University Affiliated Hospital to understand the effect of ionizing radiation on male doctors' children's gender. Local institutional review board approval was obtained, with the number 2022/80-569 from Baltalimani Bone and Joint Disease Hospital. All male physicians were asked for consent for their data to be included in the analysis. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of1975, as revised in 2008 and that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

Orthopedic surgeons, obstetricians and gynecologists, and pediatricians, practicing in university-affiliated hospitals, were contacted through one-to-one questionnaires or telephone questionnaires. Orthopedic surgeons and gynecologists were involved in the study as 2 surgical specialties, working in a similar operation room environment with orthopedic surgeons further using fluoroscopy. Pediatricians were also involved as a physician group,

MALE MEDICAL DOCTOR QUESTIONNAIRE FORM

ANONYMUS NUMBER OF THE PARTICIPANT:

1. YOUR AGE:
2. YOUR PROFESSION
   a. ORTHOPEDIC SURGEON
   b. OBSTETRICIAN AND GYNECOLOGIST
   c. PEDIATRICIAN
3. YOUR YEARS OF PROFESSION INCLUDING RESIDENCY ....
4. HOW MANY PREGNANCIES DID YOUR PARTNER HAVE .....
5. DID YOUR PARTNER HAVE ANY MISCARRIAGES BEFORE 20 WEEKS
   a. YES b. NO
6. HOW MANY .....
7. DID YOUR PARTNER GIVE BIRTH BEYOND 20 GESTATIONAL WEEKS
   a. YES b. NO
8. HOW MANY .....
9. DO YOU HAVE A LIVING CHILD
   a. YES b. NO
10. IF YES TO PREVIOUS QUESTION; HOW MANY CHILDREN DO YOU HAVE: .....
11. DO YOU HAVE A DAUGHTER
    a. YES b. NO
12. HOW MANY GIRLS DO YOU HAVE .....
13. DO YOU HAVE A SON
    a. YES b.NO
14. HOW MANY BOYS DO YOU HAVE .....
15. CAN YOU TELL THE GESTATIONAL AGE AT BIRTH OF YOUR CHILDREN
    ....
16. DO YOUR CHILDREN HAVE ANY CONGENITAL ABNORMALITY
    a. YES b. NO
17. IF YES CAN YOU NAME THE ABNORMALITY
18. DID YOU OR YOUR PARTNER HAVE ANY INFERTILITY DIAGNOSIS OR TREATMENT
    a. YES b. NO
19. DID YOU HAVE ANY ABNORMALITY IN SPERMIOGRAM IF ANY
    a. YES b. NO
20. CAN YOU NAME THE ABNORMALITY
    a. STERILITY
    b. AZOSPERMIA
    c. TERATOSPERMIA
    d. OLIGOSPERMIA
    e. COMBINED
    f. OTHER
21. DO YOU SMOKE CIGARETTES a. YES b. NO
22. DOES YOUR PARTNER SMOKE CIGARTTES a.YES b. NO
23. WHAT IS THE PROFESSION OF YOUR PARTNER
    a. HEALTH CARE
    b. OTHER THAN HEALTH CARE
    c. NOT WORKING
24. IF YOU ARE AN ORTHOPEDIC SURGEON OR OBSTETRICIAN AND GYNECOLOGIST;
    a. HOW MANY HOURS DO YOU SPEND IN OPERATION ROOM
       i. NONE
       ii. 1-8 HOURS /WEEK
       iii. 9-20 HOURS / WEEK
       iv. 21-40 HOURS / WEEK
       v. ≥40 HOURS / WEEK
25. IF YOU ARE AN ORTHOPEDIC SURGEON WHICH AREA ARE YOU MORE INTERESTED IN
       i. SPORTS MEDICINE
       ii. VERTEBRA
       iii. ARTHROPLASTY
       iv. TRAUMATOLOGY
       v. DEFORMITY AND LIMB LENGTHENING SURGERY
       vi. ONCOLOGY
       vii. PEDIATRIC ORTHOPEDIC SURGERY
       viii. HAND SURGERY
       ix. FOOT AND ANKLE SURGERY
       x. OTHER .....
26. IF YOU ARE AN ORTHOPEDIC SURGEON HOW OFTEN DO YOU USE FLOUROSCOPY
       i. 0- 5 SHOTS / WEEK
       ii. 6-20 SHOTS / WEEK
       iii. 21-50 SHOTS / WEEK
       iv. ≥50 SHOTS / WEEK

THANK YOU FOR YOUR PARTICIPATION, WE APPRECIATE YOUR COOPERATION.
AUTHORS.

Figure 1. Male medical doctor questionnaire form.

neither working in the operation room environment nor using fluoroscopy.

The questionnaire included 26 questions; with 10 open-ended, 10 yes or no questions, and 6 multiple choice questions (Figure 1).

The age of the physician and years in the field including residency were asked. Gravida, parity, and number of miscarriages of his partner were noted. If he had a live-born baby, the number of children, number of males, and number of females were recorded. The gestational age at birth, any congenital abnormality, and type of the abnormality were assessed. Any history of infertility diagnosis was questioned. The smoking habit of the couple and the profession of the female partner were asked. The hours spent in the operation room were asked to the orthopedic surgeons and obstetricians and gynecologists. Orthopedic surgeons were asked to mention their subspecialties and the frequency of fluoroscopy use per week.

The physicians with a diagnosis of infertility, any abnormal semen analysis, history of using assisted reproductive technologies (such as intrauterine insemination, in vitro fertilization, and ones requiring Testicular Sperm Extraction (TESE)) were excluded from the study. The physicians whose wives were medical workers and who had a child before starting their residency were also excluded.

Statistical Analysis

Statistical analysis was performed using the Statistical Program for Social Sciences version 22.0 (IBM SPSS Corp.; Armonk, NY, USA). Data were characterized by means ± standard deviations and percentages. Kolmogorov–Smirnov and Shapiro–Wilk tests were used for assessing normality. Parametric tests were used for variables fitted to normal distribution, and non-parametric tests were used for not normally distributing variables. One-way analysis of variance test was used for comparing continuous variables between

3 physician categories. Categorical variables were compared with Pearson χ^2 test. A multinominal regression analysis model was used to predict the probability of category membership on a dependent variable based on binary independent variables. Odds ratios (OR) and 95% CIs were calculated. A P value < .05 was considered statistically significant.

RESULTS

There were 177 physicians, who had at least 1 child born after 20 weeks of gestation, included in the study. All wives included in the study were below 37 years of age when they had given birth. The mean age was 42.19 ± 6.93 (min 29-max 63). The age and professional years spent in occupation were similar among the 3 groups (P=.428 and P=.319).

There were 80 orthopedic surgeons (45.2%), 55 obstetricians and gynecologists (31.1%), and 42 pediatricians (23.7%). Of 80 orthopedic surgeons; 17 (21.25%) were dealing with sports medicine, 5 (6.25%) spinal surgery, 20 (25%) arthroplasty, 18 (22.5%) traumatology, 3 (3.75%) deformity, 4 (5%) oncology, 5 (6.25%) pediatric orthopedics, 4 (5%) hand surgery, and 4 (5%) foot and ankle surgery. The frequency of fluoroscopy shots per week was found as follows: 25 surgeons (31.25%) had 0-5 shots/week, 10 surgeons (12.5%) had 6-20 shots/week, 23 surgeons (28.75%) had 20-50 shots/week, and 22 surgeons (27.5%) had more than 50 shots/week.

All physicians had a living child. Of pediatricians, 73.8% of them had at least 1 son; of obstetrics gynecology specialists, 74.5% of them had at least 1 son; and of orthopedic surgeons, 42.5% of them had at least 1 son.

There were 3 babies born with congenital abnormalities; they were (i) pes equinovarus deformity (orthopedic surgeons' daughter who was in the pediatric orthopedic department and had 20-50 shots/week), (ii) ventricular septal defect (son of a pediatrician), and (iii) atrial septal defect (daughter of an orthopedic surgeon who was in the arthroscopy department having 0-5 shots/week).

There were similar clinical miscarriages of 8%, 9.1%, and 8.7% among the 3 physician groups (P=.276).

The use of personal protective equipment such as protective thyroid, pelvic, and body shield during fluoroscopy shots was questioned by orthopedic surgeons and all mentioned that they are using the protective equipment while using C-arm fluoroscopy.

Orthopedic surgeons had a significantly lesser number of boys than obstetrician/gynecologists (P=.002). There was a significant difference in the number of boys between orthopedic surgeons and pediatricians (P=.030). There was no significant difference in the number of boys between pediatricians and obstetricians/gynecologists (P=.71) (Table 1).

Having at least 1 son or having no sons was analyzed between the 3 physician groups (Table 2).

Table 1. Comparing the Characteristic Data Among 3 Different Male Physicians

	Orthopedic Surgeons (n=80)	Obstetrician and Gynecologists (n=55)	Pediatricians (n=42)	P
Mean gravida	1.55 ± 0.673	1.67 ± 0.579	1.74 ± 0.587	.274
Mean parity	1.55 ± 0.673	1.67 ± 0.579	1.71 ± 0.596	.317
Mean number of living child	1.55 ± 0.673	1.67 ± 0.579	1.64 ± 0.485	.473
Mean number of sons	0.55 ± 0.727	0.98 ± 0.782	0.81 ± 0.552	.002*
Mean number of daughters	1 ± 0.727	0.69 ± 0.635	0.83 ± 0.66	.034

One-way analysis of variance was used for comparisons between 3 groups.
*P < .05 was statistically significant.

Table 2. Number of Physicians Having at Least 1 son and Total Number of Sons Among Each Group is Demonstrated

	Total (n=177)	Orthopedic Surgeons (n=80)	Obstetrician and Gynecologists (n=55)	Pediatricians (n=42)	P
Number of physicians having a daughter	123	61	33	29	.131
Number of physicians having a son	106	34/80 (42.5%)	41 (74.5%)	31 (73.8%)	.000*
Total number of sons	132	44	54	34	

Data are compared using Pearson chi-square test.
*P < .05 was considered statistically significant.

Having a daughter was not significantly different among the 3 physician groups ($P > .05$). But orthopedic surgeons had significantly lesser sons than obstetrics gynecology specialists and pediatricians ($P = .002$).

Logistic regression analysis was performed to calculate the likelihood ratio of having a son. Being a pediatrician increased the likelihood of having a son (OR: 3.813, 95% CI, 1.682-8.642, $P = .001$) when compared to orthopedic surgeons. There was no difference when pediatricians and obstetrics gynecology specialists were compared in terms of having a son (OR: 0.962, 95% CI, 0.385-2.408, $P = .935$). Frequency of fluoroscopy use and having a son analyzed among orthopedic surgeons and more than 50 shots per week decreased the likelihood of having a son among orthopedic surgeons (OR: 0.353 with 95% CI, 0.178-0703, $P = .030$).

DISCUSSION

In our study, being an orthopedic surgeon seemed to decrease the possibility of having a son. Having a son was significantly more in obstetricians/gynecologists and pediatricians. In our study to rule out the difference in X:Y-bearing sperm ratio that may occur specifically due to the operation room environment, data of obstetricians/gynecologists who also work in the operation room were compared with orthopedic surgeons. The results revealed that orthopedic surgeons had significantly lesser boys than obstetrics gynecologists. Furthermore, when ionizing radiation exposure via fluoroscopy was evaluated according to weekly doses among orthopedic surgeons, using fluoroscopy more often came up with an even lesser possibility of having a male baby.

The C-arm fluoroscopy is commonly used for intramedullary fixation of long bone fractures, evaluating fracture stability, reduction of closed fractures, removing foreign bodies, external fixation, percutaneous hardware insertion, and chemonucleolysis of diseased intervertebral disks.[12]

The dose of ionizing radiation is also important for possible effects. Doses between 0.0015 Gray (Gy) and 6 Gy are referred to as low-dose radiation. A standard C-arm fluoroscopy device emits 0.113-0.043 Gy/s ionizing radiation in a single shot. A dose of 0.113 Gy/s is produced in lateral imaging and 0.043 Gy/s in anteroposterior imaging.[13] Radiation exposure at doses as low as 0.0015 Gy (i.e., 15 rad) can suppress spermatogenesis, whereas radiation doses over 6 Gy can cause permanent azoospermia and infertility.[14]

Bloom et al[15] studied peripheral leukocyte chromosome in patients undergoing diagnostic x-rays. They revealed that there was a direct effect on circulating lymphocytes in the G_1 period of interphase. Doses of diagnostic x-rays were ≤0.0035; DNA fragments and single-ring chromosomes were found in the lymphocytes, but all were transient and disappeared after 72 hours-10 weeks.

There are limited data about the effect of radiation due to fluoroscopy on the gender of physicians' children. An important study on this issue was made by Zadeh and Briggs; they stated that the frequency of congenital anomalies in children born to orthopedic surgeons and obstetrician/gynecologists is significantly higher when compared to the normal population, but the reason for this was due to non-radiation causes. They also stated that the frequency of congenital malignancy in the same groups was not different from normal population.[16] We included pediatricians in our study to eliminate the effects of exposure to operating room conditions, which is one of the common risk factors between the 2 groups. We did not find any difference among the 3 groups for congenital abnormality of their newborns. One of the findings of the study by Zadeh and Briggs was that the frequency of having a girl in the orthopedic surgeon group was significantly higher than both the obstetrician/gynecologists and the normal population.[16] In our study, the frequency of having daughters among physicians was not different.

In the literature, there are studies on occupational radiation exposure and its effect on sperm parameters.[17,18] Kumar et al[17] observed the sperm motility changes, morphological abnormalities, DNA fragmentation, and global hypermethylation in 83 healthcare workers exposed to ionizing radiation. In the study by Zhou et al.[18] changes in sperm motility characteristics, morphological abnormalities, and DNA fragmentation were observed in 43 men exposed to occupational ionizing radiation.

Gupta et al[19] studied exposure to inhalation anesthesia gases and X- and Y-bearing sperm ratios. They observed from surveys that anesthesiologists have more daughters than sons without a clear explanation, and the significant results could be attributed to the inhalation of gases in the operation room. In our study, we included a third group consisting of pediatricians who are typically not exposed to these gases during their regular working days to eliminate the effects of anesthetic gases and other possible factors, which may be attributed to working in the operation room, on the gender of physicians' babies.

In their study about radiation exposure on larval chromosomes, Giatti et al[20] found that Y chromosome is more resistant to radiation. However, it should be noted that the situation may be different in humans. Moreover, in another study with larva, it was found that x-rays had a significant effect on the morphology of the Y chromosome.[21]

Spermiogram is susceptible to oxidative stress from various environmental factors such as cigarette smoking; electromagnetic waves, especially from cell phones or base stations; toxins; pollution; aging; any increase in temperature; and also from radiation.

The effects of these start as semen contamination with reactive oxygen species (ROS) around the head, membranes, and tail. When ROS accumulate, they bind on the surfaces of the sperm membrane, disturbing the function of the cell membrane. Dysfunction in mitochondria, sperm DNA damage, and fragmentation lead to motility abnormality, premature aging, and apoptosis.[22,23] Clinical outcome of sperm apoptosis due to ROS is sterility. From semen contamination to DNA fragmentation, there is a wide range from natural conception to unsuccessful in vitro fertilization, increased miscarriages, or sterility.

The worldwide human sex ratio is fairly consistent while males are 50.5% and females are 49.5%. However, there can be slight national imbalances among countries and regional differences.[24] The almost equal proportions of the female and male sex are of interest, and in the literature, there are studies to understand the X- and Y-bearing sperm ratio.[25] Sex allocation of offspring is a random event depending on the possibility that the sperm bearing X- or Y-chromosome will successfully fertilize the oocyte. Alminana et al[26] found out that ovarian tubes are capable of modifying the microenvironment and thus leading to the selection of either gender.

A limitation to our study was the number of physicians; further future studies with a larger number of participants are required for better speculation of the relationship between radiation dose and having lesser male babies.

In conclusion, based on our results, occupational exposure to C-arm fluoroscopy which emits low-dose ionizing radiation could negatively affect Y-chromosome bearing sperms, eventually resulting in orthopedic surgeons to have significantly lesser sons than obstetrician/gynecologists and pediatricians. Furthermore, in the group with orthopedic surgeons when frequency of exposure to fluoroscopy shots increased, the likelihood of having sons significantly decreases when compared to orthopedic surgeons having lesser shots. The gender of the baby depends on many factors, and further studies with sperm analyses and genetic analyses could be done to enlighten this topic.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Baltalimani Bone and Joint Disease Hospital (Date: March 31, 2022, Decision No: 2022/80-569).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

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Author Contributions: Concept – T.G.; Design – T.G.; Supervision – T.G.; Funding – NONE; Materials – T.G.; Data collection and/or processing – T.G.; Analysis and/or interpretation – T.G.; Literature reading – T.G.; Writing – T.G.; Critical Review – T.G.

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