Original Article *Iran J Ped Hematol Oncol. 2025, Vol 15, No 1, 371-385*

A Risk-Based Approach to Designing an Academic Research Project: Comparing the Effects of X- and Gamma-Ray Irradiation on the Lymphocytes of Blood Bags

Mahboobeh Shojaei PhD[1], Saeed Mohammadi PhD[2,3], Nader Vazifeh Shirani PhD[4], Mohsen Bakhshandeh PhD[5], Mohammad Hessam Rafiee PhD[*1]

1. PhD student, Blood Transfusion Research Center, High Institute for Research and Education in Transfusion Medicine, Tehran, Iran
2. Associate professor, Cell Therapy and Hematopoietic Stem Cell Transplantation Research Center, Tehran University of Medical Sciences, Tehran, Iran
3. Associate professor, Research Institute for Oncology, Hematology and Cell Therapy, Tehran University of Medical Sciences, Tehran, Iran
4. Assistant professor, Department of Laboratory Hematology and Blood Bank, School of Allied Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
5. Associate professor, Department of Radiology Technology, School of Allied Medical Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran

***Corresponding author:** Dr. Mohammad Hessam Rafiee, Blood Transfusion Research Center, High Institute for Research and Education in Transfusion Medicine, Tehran, Iran. E-mail: hesam.rafiee@yahoo.com. ORCID ID: 0000-0001-6850-246X.

Received: 26 July 2024 **Accepted:** 09 November 2024

Abstract

Background: The risk assessment of research projects provides a valuable approach for designing proper methodology, assuring data reliability, and accurately forecasting the resource requirements. Although X-ray irradiation has been globally recognized as a safe method for blood bag sterilization, it has not replaced gamma irradiation in Iran. To facilitate this replacement, a suitable methodology and the assessment of the intervening factors and the risks involved are required. Therefore, this study aims to evaluate the risks associated with X-ray and gamma irradiation using Failure Mode and Effects Analysis (FMEA) as a preliminary model applied in various scientific centers.

Materials and Methods: This interventional study uses FMEA to identify the failure modes in six primary processes. Severity (S), occurrence (O), and detection (D) scores were assigned to each failure mode, and their product, the Risk Priority Number (RPN), was calculated to rank the risk levels and compare the failure modes. Control and preventive measures were defined for the failure modes, and the RPN scores were re-evaluated six months later to assess their effectiveness.

Results: Twenty-two failure modes with RPN scores ranging from 24 to 360 were identified and evaluated. Through defining control and preventive measures for all the analyzed failure modes, the overall risk level was reduced from a baseline RPN of 114.36 ± 94.97 to a re-scored RPN of 12.18 ± 7.64. This represents an approximately 89.45% reduction from the baseline. The reduction in RPN was primarily due to the changes in the occurrence and then detection.

Conclusion: FMEA is a robust tool for analyzing and mitigating risks in research projects, enhancing their quality before implementation. By this method, the risks associated with replacing gamma irradiation with X-ray irradiation for blood bags can be identified and controlled, leading to the elimination of irradiation limitations for blood bags nationwide.

Keywords: Blood, FMEA, Gamma-ray, Risk assessment, X-ray

[DOI: 10.18502/ijpho.v15i1.17282]

Introduction

Millions of dollars of public funds are allocated annually to university research projects. The primary goal of these projects is to generate new fundamental knowledge, address scientific challenges, and foster innovation in industry while improving quality of life. Despite the significance of academic research, its management often necessitates a high degree of integration and order. The inherent uncertainty and complexity of university research projects makes their management particularly challenging (1). As far as their objectives and methodologies are concerned, these

projects are fraught with uncertainty and risks (2). Therefore, a deep understanding of the nature of those risks and effective risk management strategies is essential to ensure the reliability of research data and results (2, 3). Furthermore, the accurate and standardized execution of research projects and student theses is crucial for preserving the safety of researchers, the work environment, and other stakeholders. Numerous risks can arise during the course of a research project, which will compromise the validity and accuracy of the research findings, potentially interrupting the study timeline, and endangering the well-being of researchers, the workplace, and other stakeholders. Such risks may stem from factors such as project funding instability, team turnover, data accessibility (1), lack of protocols, deviations from established procedures, inappropriate activities, inadequate skill training, accidental errors, and poor record-keeping (3). Many of these risks extend beyond the purview of individual academic research teams and necessitate systemic or institutional-level responses (1). Several risk assessment methods and techniques, such as Fault Tree Analysis (FTA), Hazard Analysis Critical Control Point (HACCP), and Failure Mode and Effect Analysis (FMEA) have been introduced in industry and regulatory frameworks (4). FMEA is a proactive, systematic, and team-based tool primarily aimed at preventing errors by identifying, eliminating, and controlling the causes and effects of potential failures in a process or system (3-5). FMEA was first used by the aerospace industry in the 1960s (6), and it has been applied in healthcare systems since the 1990s (3). The use and learning of FMEA is simple and feasible in all health system-related settings. As a result, it is now considered a vital tool for quality improvement in many clinical departments of hospitals and healthcare centers (3), blood transfusion centers (7, 8), and even in university research laboratories (9). The application of FMEA in reducing the risk of incidents and errors is promising and may become a common standard for measurement and comparison, especially in clinical laboratories (10). Although risk-based thinking is a fundamental principle and requirement according to international industry guidelines (4), risk management is rarely or never employed in research projects, particularly those conducted at universities. Moreover, there is a notable scarcity of academic publications on research project risk management (1, 2). However, some universities mandate risk assessments for the work activities and laboratory environments of master's and doctoral theses, but these assessments are often limited to occupational safety and health requirements (11, 12) and do not encompass other dimensions, which suggests a gap in this area. Additionally, student projects differ from specialized projects; given their lack of experience and sometimes limited resources and funding, students may not be adequately prepared to assume risks across all aspects of their projects. In this study, the authors utilized a doctoral dissertation titled "Investigating the Impact of X-rays Generated by a Linear Accelerator on the Apoptosis and Survival of Blood Bag Lymphocytes Compared to Gamma Rays" as a case study to demonstrate the application of FMEA in risk assessment for university research projects. The primary objective of the study is to replace gamma rays with X-rays in radiotherapy devices, given the harmful effects of gamma radiation. Beyond the objective of replacing gamma rays with X-rays for the irradiation of blood components due to the hazards associated with gamma radiation (13-15), this research aims to leverage radiotherapy equipment to alleviate the nationwide restrictions on radiation exposure. However, since this approach has not been implemented already in Iran, risk

[DOI: 10.18502/ijpho.v15i1.17282]

assessment and failure mode and effects analysis (FMEA) are necessary to establish a correct irradiation setup for producing blood bags that are suitable for specific patients in hospitals and radiotherapy centers. The risk assessment of research and student projects in universities and academic centers is a useful and practical approach for designing sound methodologies and accurately forecasting resource requirements. Therefore, the objectives of this study are twofold: 1) to identify, evaluate, and prioritize the risks in a student thesis in a university setting using FMEA, and 2) to assess the impact of corrective actions after conducting FMEA. The study can serve as an initial model for the risk assessment of student theses in academic institutions across developing countries. Such assessments are expected to lay the groundwork for more rigorous future research.

Materials and Methods

This interventional study is part of a research project titled "Evaluation of the effect of X-ray radiation produced by a linear accelerator device on the apoptosis and survival of blood bag lymphocytes compared to gamma rays". The project was conducted at the High Institute for Research and Education in Transfusion Medicine, and it was approved by the ethics committee (IR.TMI.REC.1401.010) in 2022. In this project, FMEA, control and preventive measures, and 6-month monitoring were performed to achieve the research objectives which involved the following 5 stages (3-5):

Stage 1. Creating a multidisciplinary risk assessment team

Stage 2. Preparing process maps and determining potential failure modes

Stage 3. Developing a risk matrix and assigning scores to failures

Stage 4. Analysis, evaluation, and prioritization of risks

Stage 5. Defining control and preventive measures, monitoring, and re-scoring

Stage 1: Creating a risk assessment team

The risk assessment team consisted of the project supervisor, the project staff (including the student researcher), advisors, staff of the irradiation room at Tehran Blood Transfusion Center and Tehran Shohada Tajrish Hospital, nurses, and a representative from the quality control department. Based on the research project flowchart, this team was responsible for identifying the potential failure modes, the potential effects of the errors in related processes, predicting control and preventive measures, and monitoring their correct implementation.

Stage 2: Preparing process maps and determining potential failure modes

Initially, all the processes related to the study were reviewed by the risk assessment team. After several rounds of internal discussion and process evaluation, a detailed flowchart of the sequential processes/activities related to the implementation of this research project was designed. Finally, based on the team members' expertise and the previous experience of similar student projects at the institute, six main processes which had the highest risk of failure were selected (Figure 1). This allowed for a complete understanding of the individual stages involved in the process. Through brainstorming, the interdependence of the stages and the possibility of unexpected and undesirable outcomes at each stage were predicted. All the stages in the research process, including making decisions to build a special irradiation box, preparing blood bags, transporting the blood bags and their cold chain, dividing the bags, irradiation, sampling the bags, measuring the variables, and meeting the safety and health requirements were evaluated.

Stage 3: Developing a risk matrix and assigning scores to failures

[DOI: 10.18502/ijpho.v15i1.17282]

A score was assigned to each identified failure mode based on its severity (S), occurrence probability (O), and detection probability (D) (Table I). Severity refers to the consequences of a failure mode in each project phase, considering the potential damage to the product, the individuals involved, the environment, the credibility of the study results, etc. Occurrence is the probability of each predicted failure mode occurring in the study. Detection represents the probability of identifying or observing the potential causes of a failure mode. Based on the scoring table (Table I) for the three mentioned variables, a risk priority number (RPN) from 1 to 10 was determined for the failure mode risk by multiplying the three variables. For example, to calculate the risk of a failure mode with the highest severity score (10), the highest occurrence probability (10), and the lowest detection probability (10), the RPN was considered to be 1000. To calculate the probability of the failure, the data from previous adverse events and the statistics from similar projects were used

Stage 4: Analysis, evaluation, and prioritization of risks

The failure modes of project processes were scored and ranked to determine their priority and importance. RPNs < 24, 24-200, and > 200 were considered low, medium, and high risk, respectively. The highest RPNs were prioritized for control and preventive actions. The failure modes with RPN < 24 were not further investigated.

Stage 5: Defining control and preventive measures, monitoring, and re-scoring

The risk assessment team discussed the prioritization of failure modes and examined the given timeframe based on resource availability or operational control actions. The root causes of a failure mode were analyzed, and strategies were developed to prevent its occurrence in the future. For all the major failures with RPN ≥ 24, effective control and preventive measures were defined (Table II). To this end, through conducting a pilot phase and performing all its defined work processes three times on five blood bags, all the control measures were continuously monitored. If a control measure was ineffective, a new measure was defined, and re-scoring was performed to reduce the risk. For example, for the two risks of "correct recording of bag temperatures during transportation" and "sampling and testing after irradiation", the RPN was recalculated after implementing control measures. This revealed that the risk level had not decreased significantly, leading to the definition of a new control measure. Finally, all the risks were continuously monitored throughout the project. It is worth mentioning that the control and preventive measures were implemented on the purpose of reducing the risk level before the start of the research project.

Results

FMEA and baseline RPN scoring

Table II provides a complete description of the failure modes identified in this study, baseline RPN, root causes, control and preventive measures, and re-scored RPN. Thirty-five failure modes were identified by the risk assessment team, of which 22 with RPN scores ranging from 24 to 360 were analyzed. For the analyzed RPNs, the median value was 82, and their total average was 114.36 ± 94.97 (Table II). A total of 13 failure modes which were low-risk (37.14%) were not analyzed. There remained 18 failure modes with a medium risk (51.42%) and 4 failure modes with a high risk (11.42%). The failure modes with the highest RPN included a) the possibility of improper irradiation or uneven dose distribution to blood bags by the linear accelerator (RPN = 360) and b) the incorrect sampling and testing of blood bags after irradiation and during operation (RPN = 315) (Table II). Since "severity" was the most important RPN variable, the

[DOI: 10.18502/ijpho.v15i1.17282]

failure modes with the highest severity scores (S = 9 and 10) were the same as those with the highest RPN. As observed in the main processes, the frequency of the 22 analyzed failure modes in this study was 2 for Process 1, 2 for Process 2, 5 for Process 3, 5 for Process 4, 6 for Process 5, and 16 for Process 6 (Table II). Some failure modes were shared in several processes. Among the three RPN variables, the highest average score belonged to severity with the mean ± standard deviation of 6.77 ± 1.84, which was significantly higher than the values for occurrence (5.09 ± 2.15, p = 0.006) and detection (2.95 ± 1.04, p = 0.000) as calculated by ANOVA (Table II).

Control and preventive actions for medium and high-risk failure modes

Through defining control and preventive measures for the 22 analyzed failuremodes, the overall risk level was reduced from a baseline RPN of 114.36 ± 94.97 to a re-scored RPN of 12.18 ± 7.64. This represents an approximately 89.45% reduction from the baseline. The reduction in RPN was primarily due to the changes in the occurrence (from 5.09 ± 2.15 to 1.68 ± 0.55 in O score) and detection (from 2.95 ± 1.04 to 1.31 ± 0.46 in D score). The failure modes with the highest percentage of reduction in risk included a) the potential mixing of control blood bags and gamma or X-ray-irradiated blood bags during shipment to irradiation centers (94.28% reduction from baseline), b) the small sample size examined in the study (93.65% reduction from baseline), and c) the incorrect sampling and testing of blood bags during the work process (93.33% reduction from baseline) (Table II).

[DOI: 10.18502/ijpho.v15i1.17282]

Table I: Definition of Severity, Occurrence and Detection (3, 5, 8)

Index	Severity[1]	Occurrence[2]	Detection[3]
9-10	Critical wrong action in process, failure resulting in severe damage to safety of product, people (even death), environment, and invalidity of study results.	Failure is almost inevitable or very high: 1 in 20. It will happen (1 in 10-20).	Detection of a failure mode is almost impossible or very rare: there is no viable detection method.
7-8	Important impact on the performance of the process, product, or result: failure resulting in wasting of resources like product, cost, time, etc., or defects in study results	High or repeated failures: Will probably happen (1 in 50-100).	Detection of failure mode is unlikely or very low: detection method is not reliable or effective
5-6	Moderate retard in process, failure may cause minor damage: Significant impact on the performance of the process, product, or study results	Moderate or occasional failures: It may or may not happen (1 in 500-2000).	Detection of failure mode is low or moderate: Method of detection with weak or average effectiveness detection
3-4	Short retard in process without damage: Less or moderate impact on the performance of the process, product, or study results	Low or relatively few failures: It probably will not happen (1 in 10000).	Detection of failure mode is high: Detection method with high efficiency and in time of reaction
1-2	Little effect: mild or without impact on the performance of the process	Failure is unlikely or very low: It will not happen (1 in 100000).	Detection of failure mode is almost guaranteed: There are automatic detection and reaction.

1. Severity refers to the consequences of a failure mode in each project phase. 2. The occurrence is based on the reason of the error. 3. Occurrence and detection can be minimized by process and design changes.

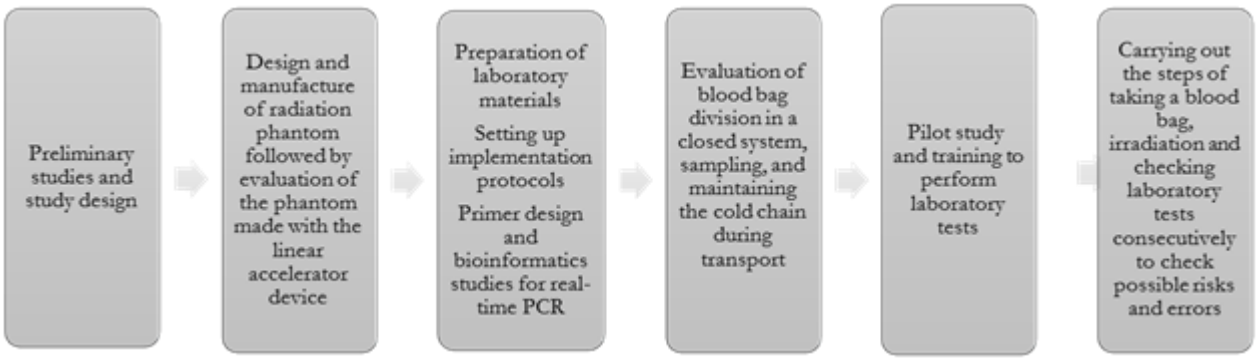

Figure 1. A flow diagram indicating the research process and the critical control points

[DOI: 10.18502/ijpho.v15i1.17282]

Table II: Analysis and assessment of risks along with control and preventive measures

NO.	Basic Function /Component	Main Process	Root Cause	Consequence	S	O	D	Baseline RPN[1]	Planned actions for control and prevention	S	O	D	Re-scored RPN	% change *
1	The possibility of insufficient funding from the High Institute for Research and Education in Transfusion Medicine	1,5	- The acquisition of raw materials and the provision of requisite conditions for project advancement are limited.	-Failure to complete the project	7	7	3	147	-Obtaining a grant from an alternative research center	4	2	2	16	-89.11%
2	The sample size examined in the study is small.	1,5	-Low budget -Lack of correct statistical analysis before starting the project	-The research results will not be reliable.	6	7	3	126	-Providing an appropriate budget as much as possible -Using appropriate model articles -Using the appropriate statistical formula to determine the sample size	4	2	1	8	-93.65%
3	The type of blood bags used is not suitable	3	-Simultaneous use of filtered and non-filtered bags in Iranian blood transfusion centers	-Impact on study results	7	8	1	56	-Not using a filter bag in the study -Determining the brand of the simple bag used in the project	5	1	1	5	-91.07%
4	The possibility of temperature elevation during the division of each blood bag into three parts.	4,6	-Keeping blood bags unrefrigerated longer than the standard time	-The possibility of bacterial contamination - Increased amount of hemolysis -Defects in the function of cells	5	3	2	30	- Optimization of procedures to minimize blood bag exposure to ambient temperature, adhering to the time constraints outlined in the validation document.	5	1	2	10	-66.66%
5	Incorrect division of each bag of maternal blood into three parts	4	- Incorrect blood bag volume distribution	- The potential influence of varying bag volumes on study outcomes during parallel	3	4	2	24	-Comprehensive student training in bag volume division -Post-divisional weight verification of the bags	3	1	1	3	-85.5%

[DOI: 10.18502/ijpho.v15i1.17282]

				irradiation with X-ray and gamma										
6	Microbial contamination during blood bag splitting	4,6	-Non-sterile blood bag splitting procedures -Failure to maintain sterility during blood bag division	-Microbial contamination and impact on test results	4	2	3	24	-Sufficient student skill training in blood bag division and welder use -Adherence to sterile equipment and lab hood protocols	4	1	1	4	-83.33%
7	Commencement of blood bag processing prior to obtaining confirmed screening results	4,6	-Delayed screening test results -Rushed work process	-The possibility of bag contamination and subsequent transmission	8	5	2	80	-Implementing a product release form and making product release contingent upon form completion	8	2	1	16	-80%
8	Potential for mixing control bags (gamma and X-ray) during transportation to irradiation facilities	3,6	- Bag labeling mistakes	Invalidation of test results	7	5	5	175	-Accurate bag labeling -Pre- and post-irradiation bag verification -Utilization of dedicated, traceable data loggers in each shipping container	5	2	1	10	-94.28%
9	Risk of blood bag temperature deviation due to uncalibrated refrigerator	6	- Expiration of calibration date -Breakdown or damage to the refrigerator during use	Damage to blood bags	7	2	3	42	-Refrigerator calibration document check -Daily refrigerator temperature monitoring - Placement of the data logger next to blood bags	5	1	2	10	-76.19%
10	Risk of temperature elevation during blood bag transportation	6	Failure to conduct a cold chain validation study and lack of ice bags in the right quantity and volume	-Risk of bacterial contamination -Increased hemolysis -Impaired cell function	7	4	3	84	- Placing the appropriate number of ice packs inside the transport box according to the validation study - Placing the calibrated data logger inside the transport box	7	2	1	14	-83.33%
11	Inaccurate temperature recording within the shipping box	6	-Elevated initial box temperature due to environmental conditions -Inappropriate data logger placement within the shipping box	-Inaccurate temperature recording and potential for blood bag damage during transport	5	5	3	60	-Pre-cooling the shipping container to approximately 10 degrees Celsius for a minimum of two hours prior to loading blood bags. -Proximal placement of the data logger to blood bags for accurate temperature monitoring.	5	2	1	10	-83.33%

[DOI: 10.18502/ijpho.v15i1.17282]

12	The possibility of blood bag leakage or damage during transportation	4,6	High pressure on and mechanical shock to the blood bag during the transfer	- Environmental contamination -Risk of occupational exposure to infectious biological material (e.g., blood)	7	2	2	28	-Comprehensive spill control and blood collection training for personnel to mitigate risks to individuals, samples, and the environment. -Inclusion of absorbent materials within the transport container.	5	1	1	5	-82.14%
13	The risk of blood bag leakage or damage during irradiation	6	Physical trauma to the blood bag during handling in the radiotherapy department	- Environmental contamination -Risk of occupational exposure to infectious biological material (e.g., blood)	8	2	2	32	-Comprehensive spill control and blood collection training for personnel to mitigate risks to individuals, samples, and the environment. - Inclusion of absorbent material and occupational safety equipment within the irradiation area	5	1	1	5	-84.37%
14	Inappropriate phantom for placing blood bag for irradiation	2	Inadequate container material and design	-Blood bag damage -Non-uniform or inadequate radiation dose distribution	7	7	5	245	-Optimization of phantom geometry, material, size, and thickness based on computational modeling and literature review. -Comparison of the constructed phantom with standardized geometry	5	2	2	20	-91.83%
15	The risk of inappropriate irradiation or inconsistent dose distribution to blood bags by the linear accelerator device	2,6	-Deviation from established blood bag irradiation protocols -Incorrect linear accelerator settings for blood bag irradiation	-No effect of irradiation on inactivation of lymphocytes	10	9	4	360	-Routine dose mapping for each irradiation exposure -Dual verification of dose maps by a device expert and a student for every irradiation -Utilization of irradiation indicators on blood bags -Quality control of the irradiation device for each work cycle -CT scan confirmation of uniform dose distribution	9	2	2	36	-90%

[DOI: 10.18502/ijpho.v15i1.17282]

16	The risk of prolonged irradiation time of the linear accelerator device	6	- User negligence	-Elevated temperature leading to blood bag damage	7	4	3	84	-User training -Operator supervision during irradiation -Irradiation time monitoring and documentation	7	2	1	14	-83.33%
17	Inadequate irradiation room temperature for blood bag processing	6	-Inadequate temperature control of the irradiation room for blood bag processing	-Elevated temperature leading to blood bag damage	7	4	3	84	- Temperature control before placing the blood bag in the irradiation room - Using a data logger to record the temperature of the room during irradiation -Control of irradiation time	6	2	1	12	-85.71%
18	The risk of different radiation times of girls' bags in two gamma and X radiation centers	6	-Geographic disparity between irradiation centers and distribution sites -Discrepancies in irradiation center operating hours -Operational constraints limiting personnel presence at multiple irradiation centers	-Possible influence on the results of laboratory tests	3	5	3	45	-Synchronized irradiation scheduling across both centers -Dedicated two-person transport teams for each irradiation center	3	2	1	6	-86.66%
19	Microbial contamination during sampling from the irradiated blood bag	5,6	-Sterilization breaches during blood bag division	-Microbial contamination and impact on test results	9	7	3	189	- Comprehensive training for the student in sample division and welder operation - Using sterile equipment and lab hood during work - Using a thioglycollate culture medium for contamination assessment	7	2	1	14	-92.59%
20	Inaccurate post-irradiation sample testing protocol	3,5,6	-Inappropriate protocol and consumable selection. -Insufficient technical expertise for test performance	Invalid test results	9	8	3	216	-Establishment of standardized protocols and appropriate consumable selection prior to initiating work. -Comprehensive documentation of all test procedures	8	1	2	16	-92.59%
21	Inaccurate post-	3,5,6	User error	Invalid test	9	7	5	315	- Appropriate training for	7	3	1	21	-93.33%

[DOI: 10.18502/ijpho.v15i1.17282]

	irradiation and in-process sample handling and testing			results					the student and related staff -Proper labeling of test tubes before starting work - Validated step-by-step procedure					
22	Laboratory equipment malfunction or calibration issues	3, 5, 6	-Equipment deterioration -Inadequate equipment maintenance -Inappropriate consumable selection	Invalid test results	7	5	2	70	-Standardization of protocols and consumable selection prior to work initiation. -Implementation of a preventive maintenance program for equipment	5	2	2	20	-71.42%
	Mean (± SD)				**6.77 (1.84)**	**5.09 (2.15)**	**2.95 (1.04)**	**114.36 (94.97)**		**5.59 (1.68)**	**1.68 (0.55)**	**1.31 (0.46)**	**12.18 (7.64)**	**-89.45%**

1. The risk priority number (RPN) = O * S * D

[DOI: 10.18502/ijpho.v15i1.17282]

Discussion

University research projects play a pivotal role in knowledge creation and serve as the foundation for product development in industry (17). Proper risk assessment can significantly improve the credibility and quality of research data and results. Although this study focused solely on a PhD dissertation, the analyzed failure modes can be applied to other academic and student projects. While many studies dealing with industrial projects(5, 6), healthcare areas(3, 5, 7, 8) , and academic research areas (1, 2, 9, 11, 18, 19) have employed FMEA for risk assessment, to the best of knowledge of the authors, this is the first study to use FMEA in a postgraduate student project in academic settings. In the main processes of the project, 22 failure modes were identified with medium to high risk levels. As control and preventive measures were defined, a significant reduction of about 89% in the baseline RPN of failure modes was achieved. This result is consistent with the findings from other FMEA studies (3, 20), although the nature of those studies was different. The present research demonstrated that FMEA can be a useful tool for identifying quality risks and minimizing the risks affecting data credibility, researcher safety, and work environment prior to the commencement of the project. In this study, control and preventive measures were implemented for 22 failure modes with medium to high risk levels based on root cause analyses. These measures significantly reduced the occurrence and detection variables, leading to a decrease in RPN. However, the severity variable, which had a higher RPN compared to the other variables, was not as effectively addressed. Reports on the use of FMEA in clinical studies, healthcare systems, and blood transfusion centers also indicate that control measures have the greatest reducing effect on the occurrence and detection variables (3-9, 19, 20). The findings of this study showed that, although the severity factor was hardly affected by control measures, the occurrence and detection variables experienced significant reductions in risk due to the appropriate control measures defined in the study. However, unlike FMEA studies in healthcare facilities or industry, the dissertation analyzed in this study had limited activities and processes, with a very low chance of repeating the activities. Therefore, the activities were under control, the probability of errors was low, and the ability to detect errors was high. This could explain the high effectiveness of the defined control measures in the RPN of the failure modes in this study. The highest RPN value and the highest severity score for the identified failure modes in this study were associated with the possibility of improper irradiation or uneven dose distribution in all parts of the irradiated bags. In fact, this was the most significant risk identified in this study. The main objective of the analyzed dissertation was to develop a suitable protocol for irradiation using a linear accelerator to inactivate lymphocytes in blood bags and prevent graft versus host disease (GVHD) in at-risk patients (13-16). Therefore, it is logical to take more control measures with different approaches so as to achieve this goal. Moreover, after the irradiation process, performing correct laboratory tests with a correct protocol and suitable equipment is essential to evaluate the irradiation performance of the linear accelerator. In the present study, the risks associated with this stage ranked second in terms of dangerousness. Four of the identified failure modes in this study were related to the working environment temperature during the transportation, activities, and storage of blood and blood samples. Therefore, one of the important aspects of this study was its focus on the cold chain. As the authors demonstrated, validating the transportation cold chain

[DOI: 10.18502/ijpho.v15i1.17282]

and effectively monitoring and recording temperatures in real-time make it possible to significantly reduce the associated risks (21). This important factor may be overlooked in similar studies and affect the validity of the research data. Therefore, it is important to predict the control points of the cold chain in a research project and define and take control measures before starting it. The three failure modes identified in this study had the most significant impacts on the invalidity of the study results. They were those listed in rows 19, 20, and 21 of Table 2. Interestingly, with the defined control and preventive measures, all the three cases showed a similar 13-fold reduction in the RPN value. They were all related to the main processes of sampling and testing, which are common to most laboratory-based studies in academic centers. In research projects, the highest severity score is assigned to the failure mode of the validity of the data and results (3). Therefore, based on the scoring method used, this failure mode had the highest severity score. Given the defined control measures, in agreement with other studies that have used FMEA (3, 8, 9, 20), this study showed how RPN value and the risk level associated with compromising study results could be reduced by giving effective skill training to project personnel, defining and developing user manuals for each method and test, and setting optimal principles for documenting the results. In some universities, the risk assessment of work activities and laboratory environments is mandatory for occupational safety and health requirements in master's and doctoral theses, and students are required to complete risk assessment forms before starting their projects (11, 18). Additionally, various studies have been conducted on the use of FMEA with respect to health and safety in laboratory environments (9, 22). One of the important aspects of this study was compliance with health and safety considerations for the project in terms of the researcher's health, the environment, and the blood product under study. Two of the predicted failure modes were the possibility of leakage or damage to the blood bags during transportation and irradiation. To reduce the level of these risks, measures such as skill training on how to handle blood spills and providing absorbent paper and personal protective equipment were taken into account, which minimized the probability of risk occurrence. In addition, two other failure modes related to the microbial contamination of the blood bags during their initial division into smaller bags and the microbial contamination during sampling from the blood bags for testing were predicted. In this regard, efforts were made to take preventive measures such as skill training for students to maintain sterile conditions when working with blood bags, using sterile equipment such as hoods and welders, and implementing the microbial culture of blood bags as a control measure. With these measures, the RPN value was significantly reduced. As reported in several studies conducted on risk assessment using the FMEA method (3, 5, 6, 8), this technique has its own limitations, which is also true about this study. The FMEA technique ranks risks exclusively by the RPN value, and the values of the parameters in the RPN structure are unreasonably overlooked, while only the final value is observed. For example, in case a variable such as severity, which is very important on its own, receives a high value while there is low probability of occurrence, the RPN structure is identified with a low risk. Of course, in this study, an attempt was made to consider the severity score separately to prioritize the failure modes. The second challenge is the scoring of RPN variables based on the qualitative and ordinal

[DOI: 10.18502/ijpho.v15i1.17282]

variables mentioned in Table 1; given the potential nature of FMEA, different scores, sometimes low or exaggerated, can be assigned. Therefore, an attempt was made to form the risk assessment team from multidisciplinary individuals related to the project. Also, two independent scoring processes were used, and then a consensus was reached through comparing the scores.

Conclusion

The goal of blood transfusion is to save the lives of patients in need. Enhancing the safety factor of blood and blood products, especially for patients in special conditions, is essential. Setting up a system that facilitates the providing of services to patients requires careful and sensitive examinations. Therefore, quality control and the study of failure modes in research involving patients are very valuable. According to the results of this study, using an FMEA evaluation model can serve as a robust method of analyzing the failure modes in research processes and as an initial risk assessment model for student theses in various scientific centers.

Data Availability

The corresponding author can make the dataset available upon reasonable request.

Ethical Considerations

The study received the approval code IR.TMI.REC.1401.010 from the Research Ethics Committee of the High Institute for Research and Education in Transfusion Medicine. Informed consent was obtained from the individual blood donors who participated in the study.

Acknowledgments

This project is part of a PhD dissertation conducted in 2023 and approved by the High Institute for Research and Education in Transfusion Medicine. We would like to thank the colleagues at the biochemistry laboratory and Innovation Center of the Blood Transfusion Research Center as well as Tehran Blood Transfusion Center for their cooperation in this project.

Authors' Contributions

M.H.R and M.S and S.M participated in developing the study idea and design. M.S. contributed to the literature review and performed the research experiments. N.V.SH and M.B were the advisers for the performance of the research. The risk assessment team also accomplished the analysis and interpretation of the results. All the authors reviewed and approved the final version of the manuscript.

Funding

The Blood Transfusion Research Center and the High Institute for Research and Education in Transfusion Medicine financially supported this research.

Conflict of Interest

There is no conflict of interests to declare regarding this study.

References

1. Paprica PA. Risks for Academic Research Projects: An Empirical Study of Perceived Negative Risks and Possible Responses. ArXiv 2103; 08048: 2021-2025.
2. Ahmed A, Kayis B, Amornsawadwatana S. A review of techniques for risk management in projects. BIJ 2007; 14(1): 22-36.
3. Lee H, Lee H, Baik J, Kim H, Kim R. Failure mode and effects analysis drastically reduced potential risks in clinical trial conduct. Drug Des Devel Ther 2017; 3035: 43-48.
4. Priede J. Implementation of quality management system ISO 9001 in the world and its strategic necessity. Procedia Soc Behav Sci. 2012; 58: 1466-1475.

[DOI: 10.18502/ijpho.v15i1.17282]

5. Toljaga-Nikolić D, Todorović M, Bjelica D. Application of the FMEA technique in a project risk analysis. EPMJ 2018; 8(2): 36-42.
6. Bahrami M, Bazzaz DH, Sajjadi, SM. Innovation and improvements in project implementation and management; using FMEA technique. Procedia Soc Behav Sci 2012; 4: 418-425.
7. Han TH, Kim MJ, Kim S, Kim HO, Lee MA, Choi JS. The role of failure modes and effects analysis in showing the benefits of automation in the blood bank. Transfusion 2013; 53(5): 1077-1082.
8. Lu Y, Teng F, Zhou J, Wen A, Bi Y. Failure mode and effect analysis in blood transfusion: a proactive tool to reduce risks. Transfusion 2013; 53(12): 3080-3087.
9. Nasrallah I, Sabbah I, Haddad C, Ismaiil L, Kotaich J, Salameh P. Evaluating the academic scientific laboratories' safety by applying failure mode and effect analysis (FMEA) at the public university in Lebanon. Heliyon 2023; 9(12): 94-98.
10. Plebani M. Errors in clinical laboratories or errors in laboratory medicine? CCLM 2006; 44(6): 750-759.
11. Zio E. The future of risk assessment. RESS 2018; 177:176-190.
12. Aven T. Risk assessment and risk management: Review of recent advances on their foundation. EJOR 2016; 253(1): 1-3.
13. Meli A, Balanant MA, New HV, Ray M, Allen E, Cardigan R. A comparison of the effect of X and gamma irradiation on red cell storage quality. Vox Sang 2022; 117(1): 39-48.
14. Davis AM, Aung HH, Costa MJ, Dennington PM, van der Wal DE, Marks DC. X-irradiation and gamma-irradiation inactivate lymphocytes in blood components. Transfusion 2021; 61(11): 3081-3086.
15. Olivo RA, Silva MVd, Garcia FB, Soares S, Rodrigues V, Moraes-Souza H. Evaluation of the effectiveness of packed red blood cell irradiation by a linear accelerator. Rev Bras Hematol Hemoter 2015; 37(3):153-159.
16. Etemad S, Ayatollahi H, Salehi M, Siyadat P, Amini N, Sheikhi M, Fani A, Ghasemi A. Relationship between Molecular Chimerism and Graft Versus Host Disease after Allogenic Hematopoietic Stem Cell Transplantation. IJPHO 2020; 10(2): 74-86.
17. Martens ML, Carvalho MM. Key factors of sustainability in project management context: A survey exploring the project managers' perspective. Int J Proj Manag 2017; 35(6): 1084-1102.
18. Larney S, Jones N, Fiellin DA, Nielsen S, Hickman M, Dobbins T. Data resource profile: The opioid agonist treatment and safety (OATS) study, New South Wales, Australia. Int J Epidemiol 2020; 49(6): 1774-1775.
19. Wiengarten F, Humphreys P, Gimenez C, McIvor R. Risk, risk management practices, and the success of supply chain integration. Int J Prod Econ 2016; 171: 361-370.
20. Najafpour Z, Hasoumi M, Behzadi F, Mohamadi E, Jafary M, Saeedi M. Preventing blood transfusion failures: FMEA, an effective assessment method. BMC Health Serv Res 2017; 17: 1-9.
21. Obermeyer Z, Pope D. Variation in common laboratory test results caused by ambient temperature. Med 2021; 2(12): 1314-1326.
22. AlShammari W, Alhussain H, Rizk NM. Risk management assessments and recommendations among students, staffs, and health care workers in educational biomedical laboratories. RMHP 2021:185-198.

[DOI: 10.18502/ijpho.v15i1.17282]