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REVIEW

Scoping Review of Vicarious Post-Traumatic Growth Among Nurses: Current Knowledge and Research Gaps

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Background: Nurses frequently experience both direct and indirect trauma, leading to significant psychological challenges. While much research has focused on the negative impacts of such trauma, less attention has been given to vicarious post-traumatic growth (VPTG). Given the high levels of indirect trauma that nurses face, understanding VPTG is crucial for mitigating its adverse effects and enhancing mental health and work efficiency.

Objective: To map and synthesize the literature on vicarious post-traumatic growth and identify key knowledge gaps in vicarious post-traumatic growth research.

Methods: This scoping review follows the approach proposed by Arksey and O'Malley. We conducted this scoping review using the methodology recommended by the Joanna Briggs Institute, supported by the PAGER framework. We searched 7 databases and gray literature on May 19, 2023 to obtain relevant research.

Results: Finally, we included 29 studies from 9 countries. There are currently no reliable data on the incidence of vicarious post-traumatic growth among nurses worldwide. There are multiple instruments available to investigate vicarious post-traumatic growth in nurses, and the vicarious post-traumatic growth inventory is more recommended. Factors affecting nurses' vicarious post-traumatic growth include coping styles, psychological factors, and social support. Indirect trauma exposure and vicarious post-traumatic growth coexist. There are currently three intervention strategies for vicarious post-traumatic growth, but none have been proven in clinical trials.

Conclusion: This is the first scoping review on vicarious post-traumatic growth, there are a lot of research deficiencies and gaps in current research on vicarious post-traumatic growth for nurses. In view of the impact of secondary traumatic events on nurses, future research should pay more attention to nurses' vicarious post-traumatic growth and promote the development of vicarious post-traumatic growth.

Plain Language Summary:

What is already known about the topic?

- Nurses are exposed to secondary traumatic events as part of their every-day work.
- Nurses experiencing these different secondary trauma exposures experience both positive and negative outcomes, but there has been less research on vicarious post-traumatic growth.
- The influencing factors of nurses' vicarious post-traumatic growth and its related survey tools are not clear yet.

What this paper adds

- Gender, trauma type, and nurses' core beliefs, self-efficacy, coping styles, and social support are influencing factors of vicarious post-traumatic growth.
- Currently, vicarious post-traumatic growth -related survey tools are roughly divided into three types, among which secondary posttraumatic growth inventory and vicarious post-traumatic growth inventory tools are specific survey tools.

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- There are various relationships between indirect exposure to trauma and vicarious post-traumatic growth, and there are differences between different types of indirect trauma exposure. However, there is basically a consensus that indirect exposure to trauma and vicarious post-traumatic growth coexist. There are currently no targeted, scalable, and repeatable interventions for vicarious post-traumatic growth.

Keywords: nurse, vicarious post-traumatic growth, secondary traumatic, scoping review

Introduction

Nurses are central to the delivery of healthcare services, frequently acting as the foremost point of communication between patients and healthcare professionals.[1] A significant portion of their working hours is dedicated to direct patient care and interaction. Due to the demanding nature of their work environment, nurses are frequently subjected to high levels of occupational stress.[2] They face not only direct trauma, such as experiencing workplace violence, heavy workload, poor working environment and tedious interpersonal relationship processing, but also indirect trauma, which involves repeatedly hearing about, witnessing, or learning about the traumatic experiences of patients and their families.[3–5] Both types of trauma exposure—direct and indirect—can significantly impact nurses' psychological well-being, leading to issues such as anxiety, depression, secondary traumatic stress (STS) and post-traumatic stress disorder (PTSD).[6,7] However, the psychological impact of indirect trauma is particularly pronounced, with STS prevalence among nurses reaching as high as 75%.[8] These adverse outcomes not only lead to reduced work performance, compromised patient safety, absenteeism, and increased turnover rates but also contribute to a general decline in nurses' overall health status.[4,8,9]

While much of the literature highlights these adverse psychological effects, studies have increasingly explored post-traumatic growth (PTG)—positive psychological changes following trauma.[10–12] Within this framework, vicarious post-traumatic growth (VPTG) has emerged as a concept distinct from PTG, describing personal growth that arises not from one's own trauma but through empathic engagement with the traumatic experiences of others.[13] Given the high levels of indirect trauma nurses are exposed to, understanding how VPTG can be fostered offers a promising approach to counterbalance these negative psychological effects.[2] VPTG can help mitigate the harmful effects of trauma exposure by enhancing emotional resilience, deepening the understanding of human strength, and improving coping strategies, thereby alleviating the psychological burden of direct and indirect trauma, improving mental health, strengthening empathy, and increasing work efficiency.[14] Given the significant impact of trauma on nurses' psychological well-being, exploring VPTG becomes essential in the nursing field to identify strategies that support mental health and resilience.

However, despite the growing interest in VPTG, research specifically focusing on VPTG among nurses remains limited. Existing studies often show inconsistencies in measurement tools and influencing factors, and the prevalence of VPTG among nurses remains unclear.[2,15–17] A systematic search revealed only one scoping review on PTG and VPTG among nurses, but it did not differentiate between these concepts or provide a comprehensive analysis of VPTG's prevalence, measurement tools, or influencing factors.[18] Currently, there is only one review specifically focused on VPTG, but while it addresses VPTG in general professionals, it does not explore the specific needs and experiences of nurses.[19] To date, reviews have failed to focus on VPTG for nurses, creating an important gap. Thus, a targeted review on VPTG among nurses is essential to fill this gap and enhance understanding in this specific context.

Given the emerging nature of research on VPTG among nurses, a scoping review is particularly suitable for this study. It provides a broad overview of existing literature, identifies research gaps.[20] Unlike systematic reviews, which focus on detailed analysis of specific issues, a scoping review maps the extent of available evidence, examines various research methods, and lays the foundation for future, more focused research.[21] This approach will enhance understanding of VPTG, inform both research and clinical practice, and guide subsequent systematic reviews. This approach is especially pertinent to this study as it addresses the current lack of comprehensive understanding of VPTG in the nursing context, and helps to identify specific needs and gaps in the literature regarding VPTG among nurses. This will enhance understanding, inform both research and clinical practice. Given the lack of systematic information on VPTG, we conducted a scoping review to compile and summarize the literature on VPTG to inform research and practice. Aggregating information across different conditions allows researchers and clinicians to gain a deeper understanding of VPTG.

Objectives

Specifically, a systematic scoping literature review was conducted to determine the size and nature of the evidence base for VPTG in nurses, to identify gaps in the literature, and to make recommendations for future research in this area. Therefore, the systematic scoping literature review was conducted to answer the following questions: (1) What is the prevalence of VPTG among nurses? (2) What assessment tools and related instruments have been used in studies of nurse vicarious post-traumatic growth? (3) What factors/antecedents may predispose VPTG among nurses? (4) What is the relationship between indirectly exposed to trauma and VPTG? (5) What interventions have been implemented for VPTG among nurses? (6) What are the gaps in research?

Methods

This study is framed by Arksey and O'Malley's scoping methodology, which consists of five methodological steps: (1) identifying the research questions; (2) identifying relevant information; (3) study selection; (4) charting the data; (5) collating, summarizing and reporting the results.[22] For the integration and reporting of findings, we followed the PAGER (Patterns, Advances, Gaps, Evidence for Practice, and Research Recommendations) framework.[23] Preferred Reporting Items for Systematic Reviews and Meta-Analysis-Scoping Reviews (PRISMA-ScR) checklist was used as a reporting guideline by the authors.[24]

Protocol and Registration

This protocol was registered on the Open Science Framework (OSF) websites (https://osf.io/zcfn9), registration, DOI: https://doi.org/10.17605/OSF.IO/AXQYH.

Eligibility Criteria

Eligibility criteria were determined using the Population, Concept, Context (PCC) framework proposed by the Joanna Briggs Institute.[25] The Population included studies on Registered Nurses (RNs), Registered Nurse Midwives, general nurses, intensive care nurses, labor and delivery nurses, psychiatric nurses, nursing assistants (eg, Licensed Practical Nurses, LPNs, and Certified Nursing Assistants, CNAs), and newly graduated nurses. Studies were excluded if they involved mixed groups of healthcare professionals (eg, doctors, nurses, pharmacists) without separate results for nurses. The Concept focused on growth resulting from another's trauma, without restrictions on the specific measurement tools used. The Context encompassed any setting, such as hospitals, clinics, and community organizations. We included only studies published in English and limited to qualitative, quantitative, or mixed methods. Reviews, editorials, concept analyses, protocols, conference presentations, commentaries, opinion papers, and letters with insufficient data for analysis were excluded.

Information Sources

A systematic search of databases in PubMed, OVID Embase, OVID PsycInfo, EBSCO CINHAL, Cochrane Library (including the Cochrane Central Register of Controlled Trials), Web of Science Core Collections and ProQuest without time limits until 19 May 2023. To broaden the scope of our search and minimize publication bias, we also included gray literature sources, such as the WHO International Clinical Trials Registry Platform portal and ClinicalTrials.gov, which allowed for a more comprehensive overview of the available evidence. Additionally, we reviewed the references of previously published articles to identify further potential studies.

Search

Under the guidance of an experienced science librarian, our research team developed and refined a comprehensive search strategy. The search used a combination of subject terms and keywords. Search terms of this review included "Vicarious Post-Traumatic Growth", "secondary posttraumatic growth" "Vicarious Posttraumatic Growth". Detailed search strategies are provided in Supplementary Text S1. There were no restrictions on the publication date or status of publication. There were no limitation search terms related to population and context. This was to ensure a comprehensive search, as

there are relatively few studies on VPTG. By avoiding these restrictions, we aimed to include as many relevant articles as possible for a thorough review.

Selection of Sources of Evidence

Once the search was complete, all identified research was uploaded to Endnote 20.0 (Clarivate Analytics, Philadelphia, PA) a software system that manages articles, duplicates upon electronic searches were removed. Two reviewers independently screened titles and abstracts according to predefined eligibility criteria based on the PCC framework. Articles that met the criteria were then evaluated by two independent reviewers for full text based on the criteria. Conflicts in both the title/abstract and full-text phases were resolved by a third reviewer.

Data Items and Charting Process

The research team developed a pre-designed standardized data collection form containing the following variables: general information (eg, authors, year of publication, study design, study setting, population characteristics, and sample size), questionnaires used for surveys, relevant influencing factors, etc., were used to plot the data. We performed a calibration exercise using the forms to ensure consistency between reviewers. Subsequently, after pilot testing of the data extraction form, teams of two reviewers independently repeated the data extraction. Disagreements were resolved by consensus. For the graphical presentation of the basic data, we chose Excel and an online charting tool (https://datavizcatalogue.com/) to accomplish this.

Critical Appraisal of Individual Sources of Evidence

The purpose of this scoping review is to provide a systematic description of the current relevant research, so risk of bias assessment is not applicable in this research.[26,27]

Synthesis of Results

For the analysis of the results text and graphs were used to present the characteristics of the included articles using mainly descriptive statistics, and the results were synthesized and grouped according to the research questions. We collated, summarized, and reported results using the PAGER framework, which consists of five dimensions reporting results in five areas: (i)patterns, (ii) advances, (iii)gaps, (iv)evidence for practice, and (v)research recommendations, providing a consistent methodology for analyzing, reporting, and translating this scoping review.

Result

Selection of Sources of Evidence

A total of 1046 articles were retrieved from seven electronic databases, and an additional 22 articles were retrieved from the Gray Literature Database and manual reference lists. After removing duplicates, 729 articles were screened for abstracts and titles, of which 14 non-English articles, and 558 irrelevant to the topic were excluded, and the final 156 articles were screened for full-text reading, and ultimately 29 studies were eligible included in the scoping review.[9,15–17,28–52] A summary of the selection of articles is provided in a PRISMA-ScR flow diagram in Figure 1. Each article excluded after full-text reading and the reasons for the exclusion are given in the Supplementary Text S2.

Characteristics of Sources of Evidence

Of the 29 included studies, 3[36,44,49] used a qualitative design, 23 used a quantitative design (21[9,15–17,31,33–35,37–40,42,43,45–48,50–52] cross-sectional studies, one quasi-experimental research[41] and one randomized controlled trial[32]), and three studies[28–30] used a mixed-methods design. The sample size of included studies ranged from 3–467, with a total of 4622 participants included in this review. Eleven studies[9,15,28–30,33,34,41,46,49,52] had theoretical modeling, four of which were based on post-traumatic growth model. Table 1 presents the detailed characteristics of included studies.

Regarding geographical distribution (Appendix Text S3), the included studies originated from 9 different countries, with major contributors being Israel[9,34,38,46–48,50,52] (n=8, 27.58%), USA[28–30,33,35,41,49] (n=7, 34.48%), Poland[16,31,32,42,43]

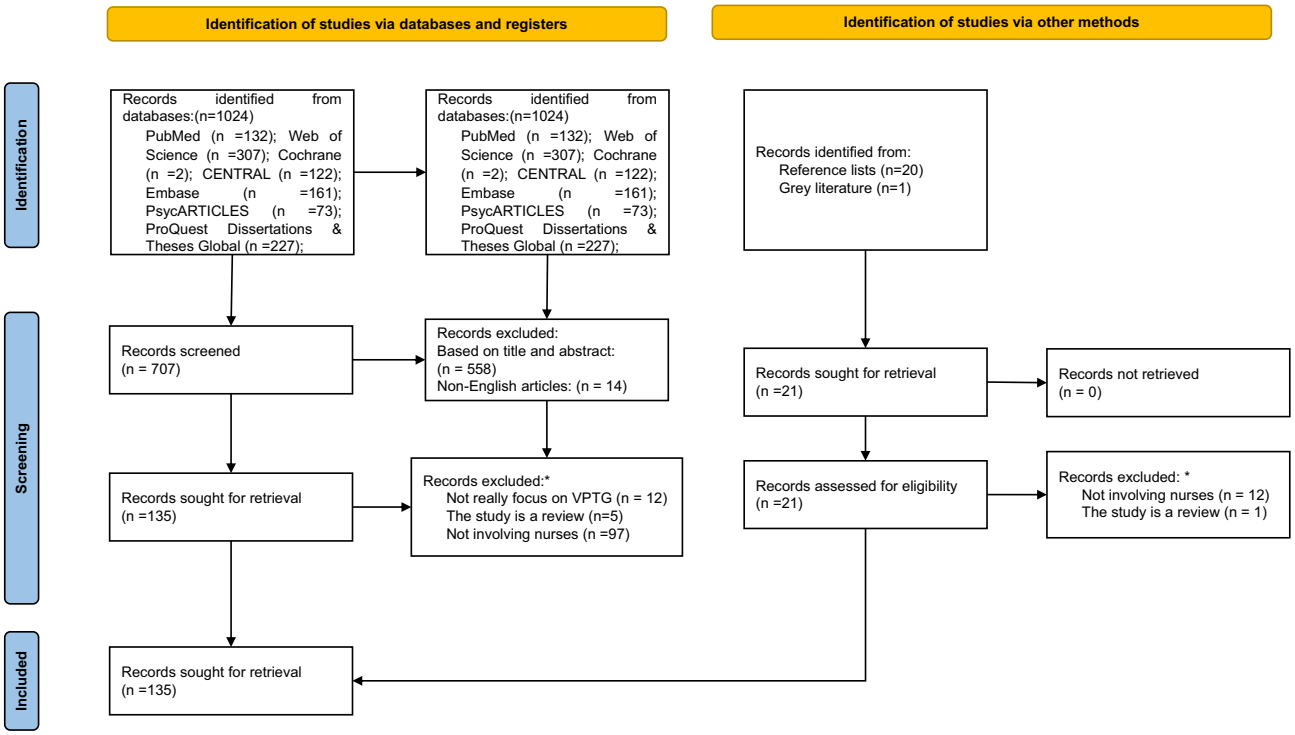

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the selection procedure.

(n=5, 17.24%), New Zealand[17,36,40] (n=3, 10.34%), China[44,51] (n=2, 6.89%), Greece[15] (n=1, 3.4%), Palestine[45] (n=1, 3.4%), Romania[39] (n=1, 3.4%), Sweden[37] (n=1, 3.4%). Over the 15-year period that spanned from the oldest to the most recent study included in this review, there was a rising trend of relevant publications, with one discrete peak year or period-2016 (6 studies, 20.7%).

Results of Individual Sources of Evidence

Table 2 summarizes the measurement tools used in the included studies, and Table 3 provides a summary for each study of the prevalence/occurrence of VPTG and the details of VPTG, as well as the risk factors/antecedents, and the relationship between indirectly exposed to trauma and VPTG. The interventions are summarized in Table 4. A summary of the analyses based on the PAGER framework is given in Table 5.

Prevalence of VPTG Among Nurse

The amount of information related to the prevalence of VPTG among nurses was scarce in the included studies. A cross-sectional study[16] survey in Poland using the SPTGI to survey 419 paramedics and nurses indirectly exposed to a range of traumatic events showed that an average of 31.06% of participants reported VPTG. Another study[43] from the same research organization that investigated the incidence of VPTG, also using the survey instrument SPTGI, surveyed 408 nurses and paramedics, and showed that as many as 40% of the respondents reported high levels of growth, while only 27.4% reported low levels of growth. A mixed study[29] from the United States investigating certified nursing midwives-(CNMs) who experienced traumatic births, CNMs Reported a small degree of VPTG. A study[15] from Greece showed that nurses indirectly exposed to confirmed cases of COVID-19 reported low to moderate levels of VPTG. Two studies[30,54] from the United States and one[52] from Israel investigated psychiatric nurses and community nurses, labor and delivery nurses and NICU nurses, respectively, and all reported moderate levels of VPTG. There is also a study[51] from China that surveyed newly graduated nurses and showed that experiencing a low level in VPTG.

Table 1 Summary of Included Studies

Author, Published Year	Country	Study Design	Publication Type	Sampling Method	Total Sample size	Sample size of nurses	Sample	Gender of Participants (Male/Female)	Age of Participants	Work Years	Work Time/ week (hour)	Theoretical Model
Beck CT, 2016[28]	USA	Mixed-methods Quantitative portion	Article	Randomization	467	467	Labor and delivery nurses	465/2	47±10.81	22 ±12.02	NR	Post-traumatic growth Model
	USA	Mixed-methods Qualitative portion		Randomization	295	295		NR	NR	NR	NR	
Beck CT, 2017[29]	USA	Mixed-methods Quantitative portion	Article	NR	425	425	Certified nurse midwives (CNMs)	9/416	51±11.28	18±10.8	NR	Post-traumatic growth Model
	USA	Qualitative portion		NR	315	315		NR	NR	NR	NR	
Beck CT, 2020[30]	USA	Mixed-methods Quantitative portion	Article	NR	109	109	Nurses	1/108	48.11±12.75	NR	NR	Revised model of posttraumatic growth
	USA	Mixed-methods Qualitative portion		NR	61	61		NR	20.25±13.25	NR	NR	
Cieslak R*, 2013[31]	Poland	Quantitative survey	Article	NR	247	NR	Nurses, paramedics	82/165	48.59±13.02	NR	NR	NR
Cieslak R, 2016[32]	Poland	RCT	Article	Randomization	168	NR	Healthcare providers**	37/131	37.49±10.39	NR	NR	NR
Doherty M, 2020[33]	USA	Quantitative survey	Article	NR	282	282	Nurses	65/217	46	NR	NR	Post-traumatic growth Model
Gurowiec, PJ, 2022[16]	Poland	Quantitative survey	Article	NR	419	419	Paramedics and nurses	31/388	39.60±11.03	12.18 ±9.74	38.64± 15.64	NR
Hamama-Raz Y, 2019[34]	Israel	Quantitative survey	Article	NR	153	153	Nurses	NR	52±10.6	19.6 ±10.3	NR	Coping Model
Hamama-Raz Y, 2021[9]	Israel	Quantitative survey	Article	NR	138	138	Pediatric nurses	0/138	43.26±11.15	16.82 ±10.84	NR	COR theory

Jennifer D, 2020[35]	USA	Quantitative survey	Ph.D.	NR	694	NR	Nurses, and medical professionals, etc.	NR	39.8±11.05	NR	NR	NA
Johal SS, 2015[36]	New Zealand	Qualitative survey	Article	Convenience	11	11	Nurses	1/11	49–64	NR	NR	NR
Kalaitzaki A, 2022[15]	Greece	Quantitative survey	Article	Convenience and snowball	647	239	Health care workers***	144/503	43.41±9.81	15	NR	Terror management theory
Kjellenberg E, 2014[37]	Sweden	Quantitative survey	Article	NR	69	NR	Nurses, physicians, physiotherapists, etc.	17/52	50.36±10.28	9.47 ±8.21	18±8.92	NA
Lev-Wiesel, R, 2009[38]	Israel	Quantitative survey	Article	NR	204	72	Nurses and social workers	63/9	43.6±10	NR	NR	NR
Măirean C, 2016[39]	Romania	Quantitative survey	Article	Self-selection	135	135	Nurses	14/121	31.28±10.77	7.46 ±6.22	33.36±7.85	NA
Manning-Jones. S, 2017[17]	New Zealand	Quantitative survey	Article	NR	365	76	Health professionals	NR	48.2	17.2	NR	NR
Manning-Jones.S, 2016[40]	New Zealand	Quantitative survey	Article	NR	365	76	Health professionals	NR	NR	22.68 ±12.53	16.66±14.31	NR
Morrissey MD, 2016[41]	USA	Quasi-experimental research	Ph.D	Randomization	18	NR	First responders*	15/3	51	NR	NR	AIP theory
Ogińska-Bulik N, 2018[42]	Poland	Quantitative survey	Article	NR	72	72	Nurses	0/72	46.01±10.69	NR	NR	NR
Oginska-Bulik N, 2021[43]	Poland	Quantitative survey	Article	NR	419	419	Paramedics and nurses	173/282	39.6±11.03	NR	NR	NR
Ren Z, 2018[44]	China	Qualitative survey	Article	NR	23	3	Psychiatric nurses, etc.	NR	25–62	3.84	32.3	NR
Shamia NA, 2015[45]	Palestine	Quantitative survey	Article	Randomization	279	279	Nurses	145/129	33.4±8.93	NR	NR	NR

(*Continued*)

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Table 1 (Continued).

Author, Published Year	Country	Study Design	Publication Type	Sampling Method	Total Sample size	Sample size of nurses	Sample	Gender of Participants (Male/Female)	Age of Participants	Work Years	Work Time/ week (hour)	Theoretical Model
Shiri S, 2010[46]	Israel	Quantitative survey	Article	NR	80	37	Nurses and rehabilitation teams	5/32	36.7	NR	NR	Cognitive orientation theory
Shiri S. 2008[47]	Israel	Quantitative survey	Article	NR	138	37	Doctors, therapists and nurses	NR	42.5	7 mouths!	NR	NR
Taubman-Ben-Ari O, 2008[48]	Israel	Quantitative survey	Article	NR	124	66	Nurses and physicians	1/66	36.2±8.4	13.2±9	NR	NA
Vishnevsky T, 2015[49]	USA	Qualitative survey	Article	Purposeful	30	30	Oncology nurses	1/29	20–60	16.3	NR	Basic grounded theory
Yaakubov L, 2020[50]	Israel	Quantitative survey	Article	NR	163	81	Nurses and physicians	25/56	37.56±8.76	8.37 ±5.82	NR	NR
Zeng L. 2023[51]	China	Quantitative survey	Article	Convenient	330	330	Newly graduated nurses	26/304	NR	NR	NR	NR
Zerach G, 2015[53]	Israel	Quantitative survey	Article	NR	196	196	Psychiatric nurses and community nurses	16/146	47.335	NR	NR	Attribution theory

Notes: *firefighters, nurses, paramedics and/or emergency medical technicians. **physicians, nurses, first responders, social workers, psychotherapists, education specialists, police officers and firefighters, and other human service provider. ***physicians, nurses, social workers, and psychologists. COR conservation of resources theory. AIP Adaptive Information Processing.

Table 2 Scales and Questionnaires Used in the Included Studies

	VPTG	Indirectly Exposed to Trauma					Other possible Relevant Factors							Direct Traumatic Events	
		Secondary Traumatic Stress	PTSD	Compassion Fatigue	Burnout	Secondary Trauma Exposure	Core Beliefs	Social Support	Cognitive Trauma Processing	Coping	Others				
Beck CT, 2016[28]	PTGI				MBI		CBI								
Beck CT, 2017[29]	PTGI						CBI								
Beck CT, 2020[30]	PTGI						CBI								
Cieslak R*, 2013[31]	PTGI-SF	STSS				STES		MSPSS							
Cieslak R, 2016[32]	PTGI-SF	STSS				STES									
Doherty M, 2020[33]	PTGI						CBI								
Gurowiec, PJ, 2022[16]	SPTGI							PWCQ	CPOTS						
Hamama-Raz Y, 2019[34]	PTGI	STSS								COPE				PNLE	
Hamama-Raz Y, 2021[9]	PTGI	PROQOL									PMPCQ				
Jennifer D, 2020[35]	VPTGI	PROQOL													
Kalaitzaki A, 2022[15]	PTGI									COPE					
Kjellenberg E, 2014[37]	PTGI	PROQOL									SASRQ	TEC	DAP-R		
Lev-Wiesel, R, 2009[38]	PTGI		PSS-I	CFST							PDEQ	PQ			

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Table 2 (Continued).

	VPTG	Indirectly Exposed to Trauma					Other possible Relevant Factors							Direct Traumatic Events	
		Secondary Traumatic Stress	PTSD	Compassion Fatigue	Burnout	Secondary Trauma Exposure	Core Beliefs	Social Support	Cognitive Trauma Processing	Coping	Others				
Măirean C, 2016[39]	PTGI	STSS						MOS							
Manning-Jones. S, 2017[17]	PTGI	STSS													TSS
Manning-Jones. S, 2016[40]	PTGI	STSS									SCUQ	HSQ			
Morrissey MD, 2016[41]	PTGI													IES-R	ISLES
Ogińska-Bulik N, 2018[42]	PTGI	STSS									RAS				
Oginska-Bulik N, 2021[43]	SPTGI	STSS						PWCQ	CPOTS		SWWS				
Shamia NA, 2015[45]	PTGI		PTSDC								PIL				GTEC
Shiri S, 2010[46]	PTGI										COQ-PTG				
Shiri S. 2008[47]	PTGI		PTSDI												
Taubman-Ben-Ari O, 2008[48]	PTGI	STSS									LOT	PSES			
Yaakubov L, 2020[50]	PTGI	STSS, ITQ													
Zeng L. 2023[51]	C-PTGI			ProQOL-CN											
Zerach G, 2015[53]	PTGI	PROQOL	PTSDI								MHLCS			LEC	ESQ

Table 3 Summary of Findings Contributed by Each Included Study

Athour, Year	Prevalence/ Occurrence of VPTG	Risk Factors/Antecedents of VPTG	Relationship Between Indirectly Exposed to Trauma and VPTG
Beck CT, 2017[29]	A small degree of VPTG	Core Beliefs: Predicts 43% of VPTG variance (P <0.001); Demographics: No significant impact on VPTG	NR
Beck CT, 2016[28]	Moderate amount of VPTG	Core Beliefs: Strongly correlated with PTGI; predicts 55% of VPTG variance.	NR
Beck CT, 2020[30]	Moderate degree of VPTG	Core Beliefs: Strongly correlated with VPTG.	NR
Cieslak R*, 2013[31]	NR	Secondary Trauma Self-Efficacy (STSE): Moderately to lowly associated with VPTG.	NR
Cieslak R, 2016[32]	NR	Self-efficacy: positively correlates with VPTG.	There was no significant association between STS and VPTG
Doherty M, 2020[33]	NR	Core Beliefs: Strong correlation with VPTG ($r = 0.675$, $p < 0.001$), explains 49.4% variance	NR
Gurowiec, PJ, 2022[16]	31.06% of participants reported VPTG	Demographics: No effect on VPTG; Social Support: Positively correlated with VPTG; Cognitive Coping Strategies: Both positive and negative correlated positively with VPTG; Workload Indicators: Not associated with VPTG; Work-Related Factors: Not associated with VPTG; Type of Events: No significant difference in SPTG based on event type (accidents, trauma/ diseases).	NR
Hamama-Raz Y, 2019[34]	NR	Exposure to Patients' Death: No significant effect on VPTG; Problem-and Emotion-Focused Coping: Linked to VPTG.	Positive significant correlation between secondary traumatization and VPTG
Hamama-Raz Y, 2021[9]	NR	Meaning in Work: Positively related;	VPTG linked negatively to STS
Johal SS, 2015[36]	NR	Focus on Positive Elements: Enhances VPTG.	NR
Kalaitzaki A, 2022[15]	Moderate to low levels of VPTG	Age: Negatively correlated with some VPTG subscales; Gender: Women scored higher on all VPTG subscales; Intrusions and Coping Strategies: Predicted VPTG.	Secondary Traumatic Stress and VPTG is positively correlated but weak
Kjellenberg E, 2014[37]	NR	Previous Trauma:Linked to higher VPTG; Work Years: Linked to higher VPTG; Exposure to Trauma Narratives: Hours of exposure not correlated with VPTG; working in a similar environment more relevant.	VPTG Positively associated with secondary stress
Lev-Wiesel, R, 2009[38]	NR	Peritraumatic Dissociation: No impact on nurses' VPTG.	PTS symptoms and VPTG co-exist
Măirean C, 2016[39]	NR	Social Support: Positively correlates with VPTG.	STS negatively associated with VPTG

(*Continued*)

Table 3 (Continued).

Athour, Year	Prevalence/ Occurrence of VPTG	Risk Factors/Antecedents of VPTG	Relationship Between Indirectly Exposed to Trauma and VPTG
Manning-Jones. S, 2017[17]	NR	NR	STS was not significantly associated with VPTG
Manning-Jones. S, 2016[40]	NR	Social Support: Significantly positively correlated with VPTG; Peer Support: Positively correlated with VPTG; Humor: Predicted 8% of variance in PTGI scores; Self-Care: Positively correlated with VPTG.	NR
Ogińska-Bulik N, 2018[42]	NR	Age: Unrelated to VPTG levels; Education Level: No impact on VPTG scores; Hospice-Based Nurses: Showed slightly higher VPTG levels; Resilience: Positively correlated with VPTG.	There was a negative relationship between STS and VPTG.
Oginska-Bulik N, 2021[43]	40% high levels of growth, 27.4% indicating a low level of growth	Gender, Age, and Occupational Group: No significant link to VPTG Job satisfaction:Positively correlated with VPTG (r = 0.23 to 0.35); Social support:Positively correlated with VPTG (r = 0.12 to 0.30); Cognitive coping:Positively correlated with VPTG (r = 0.13 to 0.52); Occupational Load: Not related to overall VPTG.	STS-VPTG Association: No linear or curvilinear association; only in nurses with <2 years experience and low workload
Ren Z, 2018[44]	NR	Existential Learning: Training in acceptance, authenticity, and mindfulness can transform suffering into VPTG.	NR
Shamia NA, 2015[45]	NR	Gender: No effect on VPTG; Traumatic Events: Positively associated withVPTG; Work-Related Events: Did not predict VPTG.	Traumatic Events and PTSD: Significantly related to VPTG
Shiri S, 2010[46]	NR	Beliefs Rooted in Optimism; Professional Affiliation; Beliefs About Goals; Professional Association and TSS; Cognitive milieu.	NR
Shiri S. 2008[47]	NR	Gender: Women experienced greater VPTG.	NR
Taubman-Ben-Ari O, 2008[48]	NR	Professional self-esteem: not found to correlate significantly with VPTG; Optimism: not found to correlate significantly with VPTG; Age: not found to correlate significantly with VPTG; Professional experience: not found to correlate significantly with VPTG; Exposure to patient death: not found to correlate significantly with VPTG; Secondary Traumatization: Positively associated with higher personal growth in individuals with low professional self-esteem.	NR
Yaakubov L, 2020[50]	NR	NR	Nurses: No overall association between ST and VPTG; emergency room nurses with low workload and experience showed a linear association.

(*Continued*)

Table 3 (Continued).

Athour, Year	Prevalence/ Occurrence of VPTG	Risk Factors/Antecedents of VPTG	Relationship Between Indirectly Exposed to Trauma and VPTG
Zeng L. 2023[51]	VPTG in the low level	Compassion Satisfaction: positively associated with VPTG.	STS Positively associated with VPTG
Zerach G, 2015[53]	Moderate amount of growth	Exposure to Violence: Positively contributes to VPTG.	Secondary Traumatization Symptoms: Positively related to VPTG in community nurses; negatively associated with PTSD and VPTG in psychiatric nurses.

Abbreviations: VPTG:Vicarious Posttraumatic Growth; ST:Secondary Trauma; STS:Secondary Traumatic Stress; PTSD:Post-Traumatic Stress Disorder.

Table 4 Interventions to Improve VPTG

Author, Year	Study Design	Intervention Content	Intervention Delivery Personnel	Intervention Dosage	Follow-up Time	Outcomes	Results
Cieslak R, 2016[32]	RCT	Education (the active control condition) and self-efficacy (the experimental intervention condition)	Had at least 1 year work experience in the context of occupational health	4 weeks	1-month follow-up; and at 2-month follow-up.	VPTG: PTGI–SF	The control (education) group participants reported higher SPTG at 1-mouth than the experimental group participants
Morrissey MD, 2016[41]	Quasi-experimental research	EMDR-IGTP	A single EMDR trained therapist	50–60 minutes	1-week follow-up;and 3-month follow-up	VPTG:PTGI	Decrease of four points in the relating to others scores (p=0.04). There were no significant differences in the other categories of new possibilities, personal strength, spiritual change, appreciation for life, and total score

Abbreviation: EMDR-IGTP:eye movement desensitization and reprocessing-integrated group treatment protocol.

Table 5 PAGER Framework

Pattern	Advances	Gaps	Evidence for Practice	Research Recommendation
Instruments to measure VPTG	Relevant survey instruments have evolved from the generalized use of the PTGI to the development of VPTG-specific questionnaires in the last two years (VPTGI as well as SPTGI)	Lack of widespread use of specific questionnaires, of which the content validity of SPTGI is unclear	There are well-validated tools to measure VPTG	1. Adding studies to test the reliability of the VPTGI and SPTGI 2. Promote the use of VPTGI
Prevalence of VPTG	Research design has evolved from mixed studies to cross-sectional as well as qualitative studies	Reliable international data are not available	Evidence to emerge from future research	Consider to use the VPTG survey tool in a unified manner and increase the relevant investigations with large sample size under different departments and different traumatic events

(*Continued*)

Table 5 (Continued).

Pattern	Advances	Gaps	Evidence for Practice	Research Recommendation
Relationship between indirectly exposed to trauma and VPTG	A number of studies already exist that note this area	Unclear relationship between indirectly exposed to trauma and VPTG	Evidence to emerge from future research	Increase high-quality studies with large samples and multiple populations
Factors/ antecedents affecting VPTG	Many studies have emerged in the last decade	1. Lack of theoretical and methodological connection between quantitative and qualitative studies 2. The influencing factors are controversial. Although studies have explored a variety of influencing factors, some factors have different ways of influencing VPTG 3. The research perspective is relatively simple and the research lacks theoretical guidance 4. The analysis methods are relatively limited, and most studies use statistical methods such as single factor analysis or multifactor analysis	Interventions may target the followings to improve VPTG: 1. Social support 2. Coping style 3. Psychological correlation factor	Theory-guided mixed-methods-based research provides a comprehensive understanding of VPTGs
Strategies/ intervention	NA	1. VPTG was not primary outcome in quasi-experimental research 2. There are no good programs to improve nurses' VPTG 3. In general, there is a lack of targeted, scalable and reproducible intervention programs	Evidence to emerge from future research	The construction of VPTG intervention scheme has feasibility and practical significance to expand the effective psychological treatment methods of VPTG.

Assessment Tools Used in Studies of Nurse VPTG

The survey assessment tools used in the included studies fall into four general categories: VPTG, indirect exposure to trauma, direct traumatic events, and some other possible relevant factors. Twenty-six of these studies used the VPTG measurement tool, broadly categorized as the Post-traumatic Growth Inventory (PTGI) and other forms of inventory based on the PTGI, the Secondary Posttraumatic Growth Inventory (SPTGI) and the Vicarious Posttraumatic Growth Inventory (VPTGI). The PTGI was used in 20[9,15,17,28–35,37–43,45–48,50–52] of these studies, one[51] used the Chinese version The Post-traumatic Growth Inventory (C-PTGI), two used the Posttraumatic Growth Inventory-Short Form (PTGI-SF). Two[16,43] of the studies use SPTGI, there is also one study[35] that uses VPTGI. Indirect traumatization consists mainly of secondary traumatic stress (STS), Post-traumatic stress disorder (PTSD), compassion fatigue, burnout, secondary trauma exposure, fourteen[9,17,31–35,37,39,40,42,43,48,50,52] of these articles investigated STS, using inventory primarily Secondary Traumatic Stress Inventory (STSS) and the Professional Quality of Life inventory (PROQOL). As for possible relevant factors, the main investigations were core beliefs, social support, cognitive trauma processing, coping. Where the

inventory used in core beliefs, cognitive trauma processing and coping are relatively harmonized there are no between-study differences. A summary of the specific information is presented in Table 2.

Factors/Antecedents Predispose VPTG Among Nurses

Among the 29 included studies, 23[9,15,16,28–34,36,38–40,42–48,51,52] conducted between 2008 and 2023 investigated various factors associated with vicarious post-traumatic growth (VPTG) in nurses, with 20[9,15,16,28–30,32–34,36,37,39,40,42–45,51,52] of these studies conducted in the last decade. The findings on the influencing factors are varied and, in some cases, controversial due to differences in theoretical and methodological approaches.

Sociodemographic Factors

Sociodemographic factors were examined in eight studies,[15,16,29,42,43,45,47] most found no significant association with VPTG, although a few indicated that gender (with women showing higher VPTG than men),[15,47] age,[15] and years of work experience[16] might influence VPTG levels.

Traumatic Event Related Factors

Seven studies[16,34,38,42,43,45,52] explored factors related to traumatic events, with mixed results: some studies found that patient death[34] and experiences of physical or verbal violence were associated with higher VPTG levels,[52] while others did not find such correlations.[16] Nurses with hospice-based nurses will have higher levels of nurse VPTGs.[42] Peritraumatic dissociation contributed to VPTG among the social workers, that peri-traumatic dissociation had no impact on the nurses' VPTG.[38]

Workload Related Factors

Workload-related factors, such as occupational load, weekly hours worked, and exposure to trauma narratives, were examined in four studies, all showing no significant association with VPTG.[16,43,45,48]

Psychological Correlation Factor

Psychological factors, investigated in ten studies, including core beliefs, optimism, psychological resilience, and self-efficacy, were generally found to be positively associated with VPTG.[9,29–33,42,46,51] Specifically, core beliefs were a significant predictor of VPTG, and self-efficacy was positively correlated with VPTG, although the relationship between secondary trauma self-efficacy and VPTG was weaker.[29,31,32] One study[9] explored "meaning in work" for nurses, including relationships, compassionate care, professional identity, and mentorship, highlighting a potential area for future research.

Psychosocial Factors

Several studies also highlighted the positive role of social support from organizations, colleagues, and positive social interactions in promoting VPTG among nurses.[16,39,40,43] Finally, coping styles were identified as crucial factors influencing VPTG,[15,16,34,36,40,43] problem and emotion-focused coping,[15,16,34,43] cognitive coping strategies,[36] and positive coping styles such as self-care and humor were all associated with higher VPTG levels.[40]

Relationship Between Indirectly Exposed to Trauma and VPTG

Research on the relationship between indirect trauma exposure and VPTG primarily focuses on secondary trauma, PTSD, and STS. Three studies confirmed a positive correlation between secondary trauma and VPTG,[31,48,52] while one study found a significant link between traumatic events and VPTG.[45] For PTSD, studies confirmed that PTSD and VPTG are correlated and coexist.[38,45] Nine studies[9,15,17,32,39,40,42,43,51] have investigated the relationship between STS and VPTG, and there is a large amount of disagreement in this area, with two studies[17,32] stating that there is no correlation, three studies[9,39,42] suggesting that there is a negative correlation, and one study suggesting[51] that there is a significant positive correlation.

Interventions for VPTG Among Nurses

Three VPTG intervention strategies were identified: face-to-face support from a quasi-experimental study,[41] and interventions providing Internet-based communication and information technology are from a randomized controlled trial.[32]

Details of these two studies are in Table 4. The Eye Movement Desensitization and Reprocessing Integrative Group Treatment Protocol (EMDR-IGTP), a face-to-face intervention, involves eight phases such as stabilizing needs, trauma assessment, desensitization, and future planning. Each session lasts 3–4 hours with 50–60 minutes of treatment, followed by check-ins at 1 week and 3 months. However, this intervention did not increase VPTG; in fact, some scores decreased.[41] Another RCT compared an interactive self-efficacy program with a read-only education program over 4 weeks. The self-efficacy group performed online exercises, while the control group accessed educational content. Results showed that the self-efficacy intervention reduced STS and increased VPTG after 1 month, whereas the EMDR-IGTP showed a decrease in specific PTGI scores.[32]

Identified Gaps in Current Research

Despite advancements in studying Vicarious Post-Traumatic Growth (VPTG) among nurses, significant gaps remain. The limited use and validation of measurement tools like VPTGI and SPTGI, particularly concerning content validity, require further research. The prevalence of VPTG largely stems from cross-sectional and qualitative studies, with a lack of reliable international data, highlighting the need for standardized tools and larger-scale studies. The relationship between indirect trauma exposure and VPTG remains unclear due to mixed findings, calling for high-quality studies with diverse populations. Research on factors influencing VPTG lacks consistency and strong theoretical frameworks, indicating the need for comprehensive, theory-based, mixed-methods approaches. Additionally, there is a shortage of targeted, scalable interventions specifically focusing on VPTG. Future studies should prioritize developing and testing effective intervention programs. Table 5 summarizes these research gaps and suggests areas for further exploration.

Discussion

To our knowledge, this study is the first scoping review to examine the available evidence on VPTG in nurses. Based on a review of 29 papers, information was summarized regarding the incidence of VPTG, assessment tools, predisposing factors/antecedents, the relationship between indirect exposure to trauma and VPTG, and what interventions are available. The PAGER framework further facilitated the research team's review of methodological or theoretical advances and gaps in each of the research questions, as well as providing contextual evidence and recommendations for practice and future research (Table 5).

Lack of Widespread Use of Specific VPTG Investigation Tools

Our review highlights that the Post-traumatic Growth Inventory (PTGI) remains the most commonly used tool to assess VPTG, utilized in 23 studies. However, PTGI's limitations, such as not distinguishing between direct and indirect trauma-induced growth, reduce its specificity for VPTG.[53,54] However, the PTGI does not adequately distinguish between growth resulting from direct and indirect trauma, which limits its applicability for assessing VPTG specifically.[55–57] The recent development of the Vicarious Post-Traumatic Growth Inventory (VPTGI) and the Secondary Post-Traumatic Growth Inventory (SPTGI) represents a significant advancement, as these tools are designed to measure VPTG with greater specificity.[16,35,43] The COSMIN (consensus-based standards for the selection of health measurement instruments) guidelines state that content validity is the most important measurement attribute.[58] VPTGI was developed on the basis of qualitative research, and there was no interference of PTGI measurement VPTG on the results. Some of these self-reported VPTG may represent maladaptive illusions created by individuals to cope with the illness. However, the VPTGI contains some negative questions, which improves the related disadvantages to a certain extent. Despite these developments, the adoption of VPTGI and SPTGI has been limited, and the content validity of the SPTGI, in particular, remains unclear.[59] The results suggest a pressing need for further validation studies to establish the reliability and content validity of these specific instruments. While there are well-validated tools to measure VPTG, expanding the use of VPTGI and conducting additional reliability studies are crucial steps to ensure accurate assessment of VPTG among nursing populations.

There is No Uniform Reliable Result on the Occurrence of VPTG in the Nurse Population

The variability in the reported prevalence of VPTG across studies can be attributed to differences in cultural contexts, study populations, and the use of diverse measurement tools. Studies utilizing the PTGI generally reported low to moderate levels of growth, whereas those using the SPTGI indicated a wider range from low to high growth levels. This discrepancy likely reflects differences in the sensitivity and specificity of the instruments used. There is no reliable data on VPTG prevalence due to inconsistent measurement scales. The PTGI lacks clear definitions for growth levels, while the SPTGI offers more clarity but is limited by small sample sizes.[60,61] Future research should use consistent tools and larger samples.

Nine studies compared VPTG among different groups, with mixed results regarding nurses and social workers.[17,38,40] One study found that nurses had higher VPTG levels than social workers, while three others found the opposite.[17,40,53] All three used the PTGI tool; two were from the same New Zealand author with consistent backgrounds and results. The third study, from Israel in 2008, may have been influenced by the context of the 2006 second Lebanon-Israel war, possibly affecting its findings. Nurses generally had higher VPTG than physicians, psychotherapists, and counselors.[40,47,48] Department-specific studies showed that maternal-newborn nurses had lower VPTG than NICU nurses, and emergency room nurses had VPTG similar to physicians.[30,50] VPTG growth domains also showed inconsistencies; some studies identified personality strengths as the highest growth area, while others pointed to relationships and life appreciation.[36,44,49] However, small sample sizes and varied study populations limit the generalizability of these findings, though they offer valuable insights for future research. Reliable data on prevalence do not yet exist, as surveys have been conducted in different countries, with different populations and different survey instruments. Considering to use the VPTG survey tool in a unified manner and increase the relevant investigations with large sample size under different departments and different traumatic events.

Some of the Influencing Factors of VPTG are Still Controversial and Require Further Exploration

There is debate over the impact of sociodemographic factors on VPTG; some studies find no link, while others show that age, gender, and experience matter. Generally, more experienced nurses handle trauma better and show higher VPTG. Older nurses, with more experience, use their resources effectively to recover and grow. An integrated approach to assessing these factors and providing early support is crucial for enhancing VPTG.[58] Challenges to core beliefs are key to VPTG, as traumatic events disrupt existing assumptions.[62,63] Professional affiliation fosters a strong sense of responsibility and identity, which boosts self-motivation and promotes VPTG in nurses.[64] Psychological resilience helps individuals manage stress and adversity. Nurses build resilience when facing indirect trauma; higher resilience leads to better adaptability and adjustment.[65] Psychological resilience can enhance VPTG with the right methods. In Bandura's Social Cognitive Theory, self-efficacy—belief in one's ability to manage actions—is crucial. Higher self-efficacy leads to greater confidence in overcoming challenges.[66] Nurses with higher self-efficacy can better promote VPTG when facing indirect trauma. Future research should focus on these psychological factors to encourage positive change after trauma. Effective coping is essential for achieving VPTG, with both problem- or emotion-focused and cognitive strategies playing a role. Positive coping styles like focusing on positives, self-care, and humor are also associated with higher levels of posttraumatic growth.[15,16,34,36,40,43] Social support, particularly from family and friends, is positively correlated with VPTG and is more impactful than support from supervisors or coworkers.[16,38,43] Effective coping and strong social support help alleviate trauma and promote growth, regardless of the type of traumatic event. Managers should implement trauma prevention plans, provide training, and improve nurses' response skills. After trauma, they should assess and mobilize support resources to aid nurses' recovery and growth.

Although studies have examined various factors influencing VPTG, the research often lacks depth in understanding how these factors interact and affect VPTG differently. There is a reliance on narrow perspectives, limited theoretical frameworks, and basic analytical methods, with most studies using simple statistical techniques like one-way or multi-factorial analyses. There is a need for more comprehensive, theory-driven research that integrates diverse perspectives and uses advanced analytical methods to understand the complex interplay of factors influencing VPTG. Developing

interventions based on a deeper understanding of these factors could enhance VPTG outcomes. Practitioners should consider multi-dimensional approaches that incorporate psychological, social, and environmental elements to better support nurses' growth after trauma.

The Relationship Between STS and VPTG Shows a Variety of Patterns

Indirect exposure to patients can lead to both STS (a negative response) and VPTG (a positive response) in trauma workers. Research on directly traumatized clients shows that PTSD and PTG can coexist.[67] Tedeschi and Calhoun's PTG model suggests that psychological stress from trauma can trigger positive cognitive strategies, promoting PTG. However, studies on the PTSD-PTG relationship show varied patterns: no correlation, positive correlation, inverse "U" correlation, and negative correlation. Given the similarities between STS and PTSD, and between VPTG and PTG, the relationship between STS and VPTG may also exhibit diverse patterns. The diversity of research groups, departments, and types of traumatic events, along with small sample sizes, leads to inconsistent results in the study of VPTG and STS. There is a lack of large-scale, high-quality studies that account for the diversity of settings and traumatic experiences, which is needed to achieve more consistent and generalizable findings. Conducting well-designed studies with larger samples and diverse settings can provide more reliable evidence, allowing for the development of tailored interventions and policies that better address the needs of trauma-exposed healthcare professionals.

Lack of Targeted, Scalable and Reproducible Intervention Programs

Currently, there are no established interventions specifically designed to improve VPTG among nurses. While many studies have explored the current state and influencing factors of nurse VPTG, only two intervention studies have been identified, highlighting that VPTG intervention research is still in its early stages. These studies have limitations, such as demographic specificity, lack of generalizability, small sample sizes, and a lack of long-term outcome analysis. Additionally, the interventions used, including educational programs and EMDR-IGTP, have shown mixed results, with a lack of replicability and insufficient consideration of the psychological needs and experiences of nurses.

There is a need for more targeted, scalable, and replicable intervention studies specifically focused on enhancing VPTG among nurses. Current interventions lack a comprehensive approach that considers the unique traumatic experiences and psychological needs of this population, and there is a need for long-term effectiveness assessments. Developing tailored interventions that are based on the specific needs and experiences of nurses is crucial. These interventions should be tested for both short-term and long-term effectiveness and be designed to be adaptable and scalable. Evidence-based programs will help ensure that the interventions are practical, acceptable, and beneficial for promoting VPTG among nurses across various healthcare settings.

Limitations

This study has some limitations. This scoping review only included articles in English and VPTG in nurses is an international issue. Based on the inductive nature of the scoping review, we did not evaluate the quality of the included studies, nor could we evaluate the quality of the gray literature. However, the inclusion of gray literature to provide the full scope of the phenomenon under study is also a strength of the scoping review. There are some strengths to this study, however, in that we used the PAGER framework to provide evidence for practice and research recommendations, making it easier for future researchers to get a holistic view of the VPTG problem.

Conclusions

This scoping review of VPTG among nurses highlights key insights and research gaps. The VPTGI is the most recommended tool for assessing VPTG due to its specificity, but further validation of instruments like the SPTGI is needed. VPTG prevalence among nurses ranges from low to moderate, influenced by social support, coping styles, and psychological factors such as core beliefs and self-efficacy. However, more theory-driven approaches are needed to understand these relationships better. While some interventions, such as educational and self-efficacy programs, show promise, they are limited by small sample sizes and lack of long-term evaluation. Future research should prioritize standardized tools, robust study designs, and theory-based interventions to enhance VPTG, support nurses' mental health, and build resilience against indirect trauma.

Implications for Practice

Healthcare institutions should regularly assess VPTG among nurses using standardized tools like the VPTGI and develop targeted interventions to enhance social support, adaptive coping strategies, and psychological resilience. Policymakers need to implement evidence-based programs that promote a supportive work environment with access to mental health resources, peer support, and resilience training. Additionally, interventions should be designed to be scalable, reproducible, and customizable, combining face-to-face support with digital tools to address diverse needs in various nursing settings.

Data Sharing Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Ethical Approval

A scoping review not involves human subjects, human material, human tissues or human data. Therefore, the approval of an ethics committee was not necessary.

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This paper was uploaded to ResearchGate at https://www.researchgate.net/ as a preprint but has now been withdrawn from this site.

Author Contributions

All authors significantly contributed to the study's conception, design, execution, data acquisition, analysis, and interpretation; participated in drafting, revising, or reviewing the article; approved the final version for publication; agreed on the journal choice; and are accountable for all aspects of the work. Specifically, Yitong Cai was responsible for Conceptualization, Methodology, Software, and Formal Analysis; Yitong Cai, Ming Liu, and Chaoran Qu contributed to Validation, Resources, and Data Curation; Yitong Cai and Weixiang Luo conducted the Investigation; Yitong Cai handled Writing - Original Draft, while Yitong Cai and Jingping Zhang were responsible for Writing - Review & Editing; Jingping Zhang and Weixiang Luo worked on Visualization; Jingping Zhang and Chaoran Qu supervised the study and managed the project; and Chaoran Qu secured the Funding Acquisition.

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