Age-occurrence and interconnection of pelvic-perineal injuries in prepubertal and adolescent survivors of sexual abuse in conflict-affected settings: a retrospective study

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Summary

Background The age when pelvic-perineal injury patterns shift after child sexual abuse has not been formally identified, hindering development of age-specific examination protocols, especially in conflict zones with severe injuries and limited expertise. This study aimed to determine the association between age and pelvic-perineal trauma prevalence, identify the age threshold where injury patterns shift, and compare injury co-occurrence before and after this threshold.

Methods Medical records of 5692 females <18 years treated for sexual assault at Panzi Hospital, Democratic Republic of Congo in 2003–2020 were analyzed. Six injury types (hymenal, perineal, vaginal, anal, rectal, Douglas pouch) were examined by age. Eight analytical methods identified age threshold without prior assumptions. Injury co-occurrence before and after this threshold was compared.

Findings Methods converged on 9–11 years; age 10 was selected and validated using menarche data (>98% of ≤10 group pre-menarcheal; 99.4% of >10 group post-menarcheal). All injuries except vaginal were more prevalent in the ≤10 group. Injury burden was higher prepubertally with 4–6 concurrent sites occurring in the ≤10 group (1.85 vs 1.18; d = 0.59). Network analysis showed anal injury was central prepubertally (EIF = +16.92) and vaginal injury central post-pubertally (+10.79). The perineal–anal association reversed from positive (+2.82) ≤ 10 to negative (−6.16) thereafter.

Interpretation Age 10 marks two distinct injury profiles. Prepubertal trauma is multifocal with an anal focus, whereas adolescent trauma centers on vaginal injury with sparser patterns. These findings support age-stratified examination protocols, including systematic ano-rectal assessment in prepubertal cases and vaginal-focused evaluation in adolescents.

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Keywords: Child sexual abuse; Anogenital injuries; Pelvi-perineal injuries; Prepubertal; Network analysis; Adolescents; Conflict-related sexual violence

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Research in context

Evidence before this study

Evidence regarding age-specific patterns of anogenital and pelvic-perineal injuries following sexual assault in prepubertal and adolescent females is limited and inconsistent. A review of the existing literature was conducted through searches in PubMed, Scopus, and relevant forensic and pediatric journals, without language or date restrictions, up to December 2025. Search terms included combinations of "child sexual abuse," "anogenital injuries," "prepubertal," "adolescent," "pelvic trauma," "conflict settings," and "age patterns." While previous studies have documented differences in injury patterns between prepubertal and adolescent sexual abuse survivors, findings have been inconsistent: some studies have reported higher injury detection rates in adolescents, while others have indicated greater severity and prevalence in younger children. The precise age threshold at which these patterns shift remains undefined. Most prior research has relied on small clinical samples from high-income, non-conflict settings, with limited data from conflict-affected populations, where extreme and weaponized sexual violence produces more severe and complex injuries. Critically, no study has applied data-driven, assumption-free methods to identify a specific age threshold or to examine how injury co-occurrence patterns and their interconnectedness differ across developmental stages in this vulnerable population.

Added value of this study

Using eight convergent analytical methods applied to 5692 cases from the eastern DRC, this study identified age 10 years as a data-driven threshold separating two distinct pelvic-perineal injury profiles. Prepubertal cases (≤10 years) present with more frequent and more complex injuries, with the anus as the primary anatomical entry point; adolescent cases (>10 years) show a vaginal-centered injury pattern with fewer concurrent sites. Network analysis (applied for the first time to anogenital injuries) reveals that these are not merely differences in prevalence but reflect fundamentally different injury architectures, with a clinically significant reversal of the perineal-anal co-occurrence pattern across age groups. Menarche data confirm that this statistical threshold closely approximates the pre-/post-pubertal transition.

Implications of all the available evidence

The identification of a reproducible, biologically validated age threshold has direct implications for forensic and clinical protocols. Clinicians examining prepubertal survivors should systematically assess anal and rectal injuries, which serve as the primary entry point and may extend to deeper pelvic structures. In adolescents, vaginal examination should be prioritized. These distinct profiles should inform the development of age-specific examination guidelines, training curricula, and medicolegal documentation standards, particularly in conflict-affected settings, where specialized expertise is scarce.

Introduction

For over three decades, armed conflict in the Democratic Republic of Congo (DRC) has fueled the systematic use of sexual violence as a weapon of war, with children among the most affected populations.[1] Pelvic-perineal injuries resulting from child sexual abuse range from superficial abrasions to deep lacerations involving anogenital and intraperitoneal structures, and can lead to long-term gynaecological morbidity, incontinence, fistulas, and psychological sequelae.[2–4] Similar patterns have been documented in other conflict-affected regions.[5,6]

Current evidence indicates that injury patterns differ between pre- and post-pubertal individuals, reflecting developmental changes in pelvic anatomy and tissue characteristics.[7] While most studies have reported higher injury detection rates in adolescents,[8–11] several clinical cohorts have found frequent and more severe injuries in younger children.[12,13] However, two critical gaps persist. First, the precise age at which the injury profile shifts remains undetermined.[7,14] Prior studies have relied on a priori pubertal classifications rather than data-driven threshold identification. Second, lesions have been studied in isolation; the co-occurrence relationships between concurrent injuries at different anatomical sites have not been examined, despite clinical observations that pelvic-perineal trauma in young children is often multifocal, involving several structures simultaneously.[2,3,15]

Understanding how anogenital injuries vary by age is essential for clinical management, particularly distinguishing between normal and abnormal findings when abuse is suspected.[14] However, many clinicians lack familiarity with pediatric genital anatomy and age-related injury patterns, a gap that is especially pronounced in conflict-affected regions like Eastern DRC, where conflict-related sexual violence has caused widespread harm among children with persistent sequelae into adulthood.[4] This lack of age-related data impedes the development of appropriate diagnostic methods, treatments, and reparations for affected individuals.

To address these gaps, we conducted a cohort study of 5692 cases <18 years in Eastern DRC with the following aims: 1) to determine the association between age and prevalence of pelvic-perineal trauma, identifying the age threshold at which injury patterns shift through a convergence of multiple data-driven methods, and 2) to characterize the co-occurrence structure of injuries across anatomical sites using network analysis, comparing patterns before and after the identified threshold. We hypothesized that injury prevalence is inversely proportional to age, with a threshold at puberty, and that the nature and distribution of anatomical primary site of injuries differ before and after this threshold.

Methods

This retrospective study reviewed medical records of sexual abuse patients treated at Panzi Hospital (PH) in Eastern DRC, a center known for its comprehensive medical and psychological care and socioeconomic and legal support. Since 1999, Panzi Hospital has treated 87,380 cases, 38% of whom were minors.[16] Its multidisciplinary team reports good outcomes in 91% of rape-related injury cases.[3,17]

Study population

Data from 5692 cases <18 years who received medical care for sexual assault between 2003 and 2020 and had complete medical records were examined. Of 22,579 initially identified cases, 16,617 were excluded due to losses related to transitions in data storage systems (Fig. 1). Although not exhaustive, the final sample was adequate for robust analysis across all assault types. Participants were predominantly from Democratic Republic of Congo, including North and South-Kivu, Maniema, Tanganyika, Haut-Katanga, Lomami, Tshopo, Ituri and Kinshasa provinces with some arriving from neighboring countries, including Burundi and Central African Republic. Reporting followed STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

Procedures

All individuals provided written informed consent through a parent/guardian and their own assent to access data from their medical records. Examinations were conducted by gynecologists, pediatric surgeons, and trained medical staff who had received specific training in assessing the various types of injuries and the nature of the assault at a specialized, protocol-driven center adhering to the Istanbul Protocol.[18]

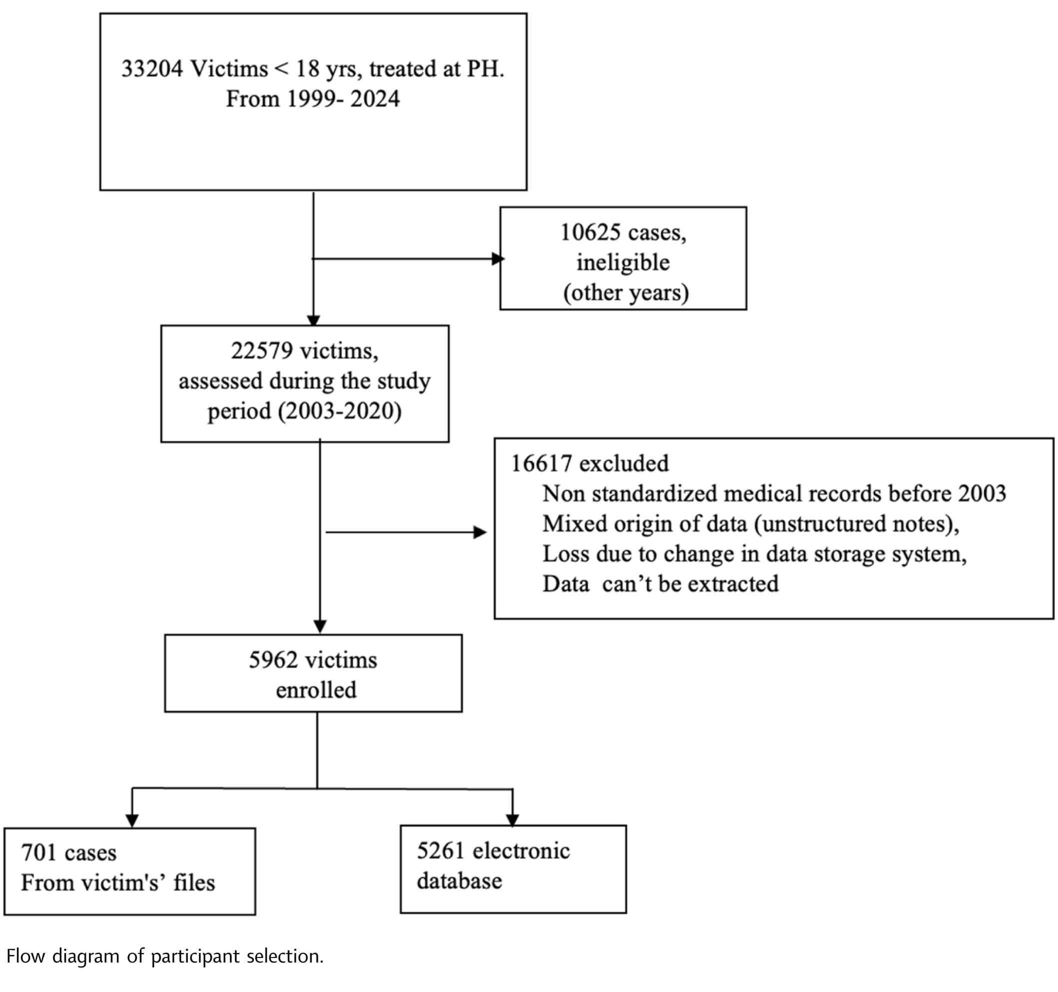

Fig. 1: Flow diagram of participant selection.

Anogenital examinations were performed with or without anesthesia, depending on the severity of the injury. Findings were documented using standardized pictograms[15,19] and classified according to Adams' nomenclature and the Mukwege classification for suspected abuse in children under five years of age.[2,15] Medicolegal evidence was collected, and comprehensive care provided by a multidisciplinary team following the model established at Panzi Hospital.

Variables recorded

Sociodemographic variables included age at abuse, age at menarche, occupation, place of residence, time to consultation within 72-h, and mode of arrival at the hospital. Age was recorded in months and years according to standard clinical documentation practices. For analysis, age was converted to completed years (0–17 years), with infants under 12 months categorized as age 0.

Clinical variables included vaginal bleeding, vaginal discharge, pelvic-perineal pain, and fecal/urinary incontinence. Both acute and chronic injuries were considered. "Pelvic-perineal injuries" refer to injuries to organs in the pelvic and perineal areas, including the anus, rectum, vagina, Douglas pouch, perineum, and hymen. The term "anogenital" specifically denotes lesions to the anus and external genitalia, while "genital" is used in reference to past publications employing this terminology.

Injuries were categorized according to standardized classifications[20,21]: superficial abrasions (confined to the epidermis), deep abrasions/contusions (extending into the dermis or underlying tissue), lacerations (full-thickness tears), and fissures/tears (linear tissue disruptions, particularly in the hymen or anal mucosa). Douglas pouch injuries were defined as deep posterior vaginal ruptures extending into the rectouterine pouch, often with peritoneal or rectal involvement. Injury categories were not mutually exclusive.

Erythema (redness) was documented but not interpreted in isolation as evidence of trauma. Consistent with the 2023 Adams update,[2] which classifies erythema among findings commonly attributable to non-traumatic conditions, it was considered a traumatic finding only when concurrent with additional injuries, such as abrasions, lacerations, or bleeding, and after exclusion of alternative etiologies, including dermatitis and infection. Isolated erythema was therefore not classified as abuse-related, in accordance with expert consensus recognizing its unclear significance.

Statistical analysis

Analyses were conducted using R (version 4.5.2; packages: bootnet, qgraph, IsingFit, NetworkComparisonTest, sandwich, boot). We first compared mean age between participants with and without each injury type using Welch's t-tests, Benjamini–Hochberg correction, Cohen's d, and 95% confidence intervals, quantifying the magnitude of group differences. Although age was non-normally distributed (Shapiro–Wilk $p < 0.001$), the Welch's t-test is robust with large samples. Then, multiple linear regression predicted age from the binary presence of each injury type. Results were validated using heteroscedasticity-consistent standard errors, robust M-estimation, and non-parametric bootstrap; all yielded consistent results. Variance inflation factors (all VIF <1.43) confirmed absence of multicollinearity. Effect sizes are reported as partial omega-squared (ω^2p).

To capture overall injury burden in a single metric, we computed an injury index as the total number of anatomical sites involved (range 0–6) for each participant. Rather than relying on a single method, we employed a convergence approach using complementary techniques to identify age threshold: (1) segmented regression with Davies test for a formal breakpoint; (2) regression trees (CART), which identify optimal data-driven splits; (3) sensitivity analysis comparing Cohen's d across all dichotomous cut-offs from 5 to 15 years; (4) reverse Helmert contrasts (comparing each age to the pooled mean of preceding ages); (5) Generalized Additive Model (GAM) with a thin-plate regression spline was fitted to estimate the non-parametric relationship between age and injury count (the first derivative of the fitted smooth identified the age of maximum decline), (6) A Bayesian changepoint analysis computed log Bayes factors under a normal-inverse-gamma conjugate model over all candidate changepoint positions, yielding a posterior probability distribution over τ, and finally (7) dichotomized group comparison ($\leq$10 vs > 10) with Welch t-test and (8) chi-square.

Although the injury index is a count variable (range 0–6), the variance-to-mean ratio was 1.04, indicating near-equidispersion. Linear models were retained as the primary specification for interpretability. Moreover, four of the eight convergence methods (Cohen's d, reverse Helmert contrasts, CART, and chi-square) are distribution-free and require no parametric assumptions about the outcome variable. Nevertheless, we conducted comprehensive sensitivity analyses comparing linear regression with Poisson, negative binomial, quasi-Poisson, zero-inflated Poisson, and ordinal (cumulative link) models.

To characterize the co-occurrence structure of injuries, we estimated separate network models for the $\leq$10 and >10 groups using the Ising model, designed for binary data. In this framework, each injury type is a node; edges represent conditional associations (co-occurrence) after controlling for all other injuries (partial correlations). Edge weights were estimated using eLasso regularization. The conservative AND-rule retained an edge only when selected by both connected nodes' regularized models. The extended

Bayesian Information Criterion (EBIC, γ = 0.25) governed model selection. Stability was assessed per Epskamp, Borsboom, and Fried (2018).[22] Edge weight accuracy was evaluated using a non-parametric bootstrap (1000 iterations) with 95% CIs. Centrality stability was assessed using a case-dropping bootstrap (1000 iterations); the CS-coefficient quantifies the maximum proportion of cases that can be removed while maintaining r $\geq$ 0.70 with original centrality ($\geq$0.25 = interpretable; $\geq$0.50 = good). Bootstrapped difference tests assessed which edges and node strengths differed within each network. Group comparison used the Network Comparison Test (NCT, 5000 permutations, van Borkulo et al., 2021)[23] to assess global strength and edge invariance (Benjamini–Hochberg corrected). Additionally, phi coefficients with Fisher's z-transformation were used to test edge-level group differences. Two centrality indices were computed: strength and expected influence (EI). We define a 'hub' as the node with the highest expected influence within its respective network, as EI is considered the most appropriate centrality metric for networks where edges can be both positive and negative (Robinaugh et al., 2016).[24] As a sensitivity analysis, networks were re-estimated under the more liberal OR-rule, which retains an edge if selected by either node's model, to assess the robustness of key findings to this methodological choice. For the results concerning network analysis, we followed the reporting standards proposed by Burger et al. (2023).[25]

Ethical approval

This study was approved by the National Ethics Committee for Health (CNES/DP-SK/199PP/2022) and conducted in accordance with the Declaration of Helsinki.

Results

Sociodemographic and clinical characteristics of the participants

Of 5692 cases (Fig. 1), average age was 13.32 years (SD 3.97, median 15, range 4 months–17 years). Older ages were overrepresented (IQR 12–16 years); less than 10% were under six, whereas 50% were $\geq$15-years. Age at menarche was available for 1271 participants (22.3%), predominantly older adolescents (median age at examination 16 years, IQR 15–17). Median age at menarche was 13 years (IQR 12–14; mean 13.1, SD 1.2; range 9–17). Only 1.8% of participants with available data reported menarche at or before age 10.

Nearly two-thirds (3754, 66.0%) sought care within 72-h post-exposure. Most arrived alone or with a family member (3186, 56.0%), while some were transferred from health facilities (123, 0.2%) or other charities, civil society organizations, or police (2383, 43.8%).

Superficial lesions included multifocal hymenal (2493, 43.8%), perineal (155, 27.3%), and anal injuries (575, 10.1%). Deep pelvic trauma included vaginal (2764, 48.6%), rectal (64, 1.1%), and pouch of Douglas injuries (18, 0.3%). Surgery was performed for deep injuries in 43.6% (2480) of cases with four deaths.

Injuries in relation to age

We compared mean age of participants with and without each injury type (Supplementary Table S1, Fig. 2). Participants were younger when there were hymenal, perineal, anal sphincter, rectal, and Douglas pouch injuries rather than no injury. Vaginal injuries occurred more often in older cases. All rectal injuries co-occurred with anal injuries, whereas only 11% of anal injuries involved the rectum.

Robust regression analyses confirmed these patterns (Table 1; model R^2 = 0.30, F (6.5685) = 398.6, p < 0.0001). Presence of hymenal, perineal, anal, and rectal lesions were associated with younger age. Vaginal injuries were associated with older age. Douglas pouch was non-significant (n = 18). OLS and bootstrap estimates differed by less than 0.03, and all four estimation methods (OLS, HC3, Huber, and bootstrap) yielded qualitatively identical significance patterns. The largest age reductions were associated with rectal (B = −4.21) and perineal trauma (B = −3.89), corresponding to approximately four-year decreases from the baseline predicted age. Anal injuries were associated with a reduction of approximately 3.5 years (B = −3.51), while hymenal lesions corresponded to a smaller reduction (B = −0.47). Vaginal injuries were associated with an increase of approximately 3.5 years (B = +3.42).

Progression of sexual assault injuries in relation to age

Eight independent methods converged on the 9–11-year range as a critical transition zone (Table 2). Segmented regression found no statistically significant breakpoint, suggesting instead a gradual transition. CART regression analysis independently identified age 9.5 as the optimal split for mean injury count (1.91 vs 1.19 injuries; n = 961 vs 4731). Sensitivity analysis showed peak Cohen's d at age 9 (d = 0.63), stable through age 10 (d = 0.59), declining thereafter (Supplementary Table S2). As shown in Fig. 3, reverse Helmert contrasts pinpointed age 10 as the first significant divergence from the preceding pooled mean (contrast = −0.384, t = −2.89, p = 0.004), with a major drop at age 11 (contrast = −0.743, t = −6.67, p < 0.001). A generalised additive model confirmed the non-linear relationship between age and injury count (F = 45.95, edf = 6.75, p < 0.0001; Fig. 4, Supplementary Table S3). The first derivative of the fitted smooth identified age 10.3 years as the point of maximum decline in injury count (−0.24 lesions per year), with inflection of the

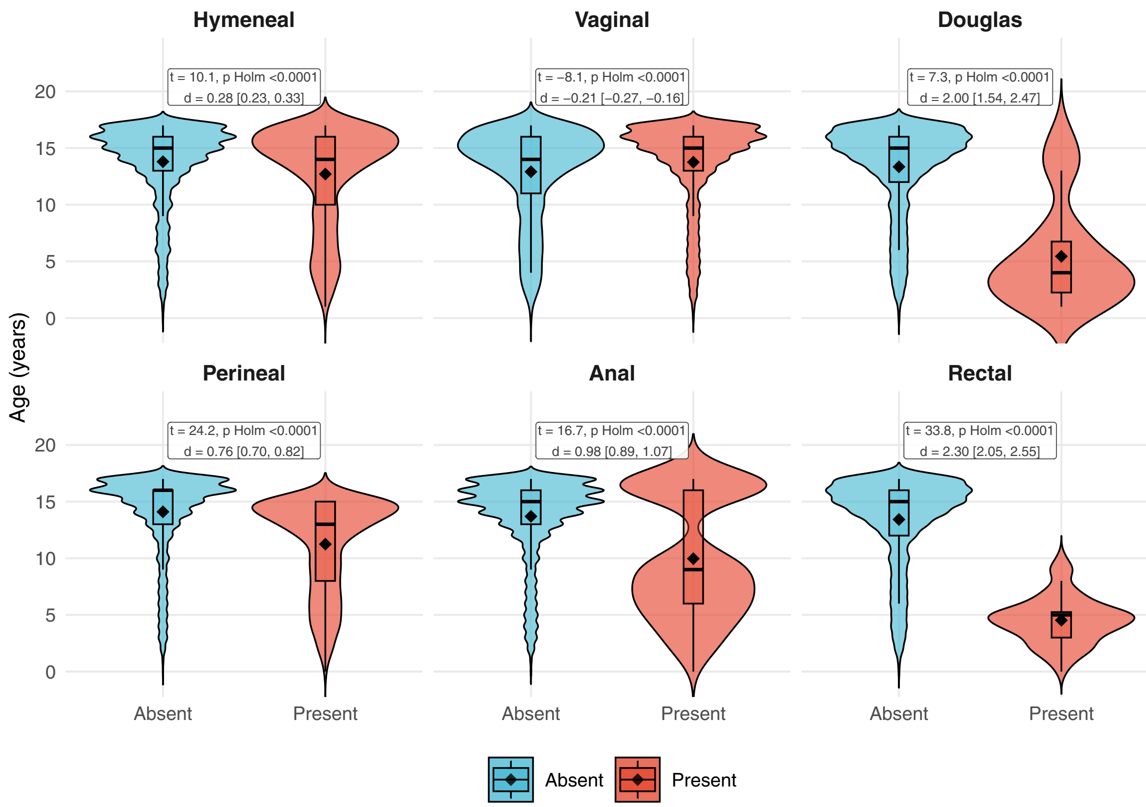

Fig. 2: Violin plot comparison of distributions (Welch's t-test).

curvature occurring at the same age. Bayesian change-point analysis concentrated the highest posterior probability for a mean shift within the 9–11-year interval (cumulative $p = 0.29$).

Based on this convergence, we adopted ≤10 vs > 10 years as the primary grouping. Cohorts differed substantially: ≤10 ($n = 1121$; $M = 1.85 \pm 1.73$ injuries) vs > 10 ($n = 4571$; $M = 1.18 \pm 0.94$; $t_{Welch}(1284) = 12.58$, $p < 0.0001$, $d = 0.59$ [0.53, 0.66]). Chi-square cross-tabulation was highly significant ($\chi^2(6) = 1448.86$, $p < 0.0001$, $V = 0.505$), with 4–6 injury sites almost exclusively in the ≤10 group.

We conducted comprehensive sensitivity analyses (Supplementary Table S4) comparing linear regression with Poisson, negative binomial, quasi-Poisson, zero-inflated Poisson, and ordinal (cumulative link) models. All models confirmed a significant negative association between age and injury count (all $p < 0.0001$). The

	B		Standard error				HC3 inference		Bootstrap		Effect	
	OLS	Huber	OLS	HC3	Huber	Boot	95% CI	p	95% CI	p	ω^2p	Size
(Intercept)	13.33	14.27	0.07	0.08	0.05	0.08	13.16 to 13.50	<0.0001	13.16 to 13.49	–	–	–
Hymenal	−0.47	−0.38	0.09	0.09	0.06	0.09	−0.64 to −0.29	<0.0001	−0.64 to −0.29	<0.0001	0.004	Negligible
Vaginal	3.42	2.60	0.11	0.09	0.08	0.09	3.24 to 3.60	<0.0001	3.24 to 3.60	<0.0001	0.155	Large
Douglas	−0.75	−0.84	0.88	0.54	0.63	0.53	−1.80 to 0.30	0.1600	−1.81 to 0.29	0.1500	0.000	Negligible
Perineal	−3.89	−3.65	0.12	0.10	0.08	0.10	−4.09 to −3.70	<0.0001	−4.08 to −3.70	<0.0001	0.164	Large
Anal	−3.51	−3.36	0.17	0.16	0.12	0.16	−3.82 to −3.20	<0.0001	−3.83 to −3.20	<0.0001	0.073	Medium
Rectal	−4.21	−4.87	0.49	0.31	0.35	0.30	−4.82 to −3.60	<0.0001	−4.80 to −3.61	<0.0001	0.013	Small

B = unstandardised coefficient (OLS and Huber M-estimator). SE = standard error: OLS = classical; HC3 = heteroscedasticity-consistent; Huber = robust M-estimator; Boot = bootstrap (10 000 iterations). HC3 inference: 95% CI and p from HC3 robust SE. Bootstrap: percentile 95% CI and two-sided p. ω^2p = partial omega-squared: <0.01 negligible, 0.01 small, 0.06 medium, ≥0.14 large (Kirk, 1996). $R^2 = 0.296$, adj. $R^2 = 0.295$, $\omega^2 = 0.295$, $F(6,5685) = 398.6$, $p < 0.0001$.

Table 1: **Multiple regression predicting age from lesion presence (N = 5692).**

Method	Approach	Identified threshold	Statistical evidence
Segmented regression	Broken-stick model (1 breakpoint)	NA	Davies p 0.71; R^2 = 0.055
CART regression tree	Recursive partitioning (depth = 1)	≤9.5	First split, cross-validated
Sensitivity analysis (max |d|)	Welch t across cut-offs ≤5–≤15	≤9	d = 0.63 [0.56, 0.70]
Reverse Helmert	Each age vs mean of all previous	Age 10	t = −2.89, p 0.0042
GAM (max |f′|)	Thin-plate spline, first derivative	10.3	F = 45.95, edf = 6.75, p < 0.0001
Bayesian changepoint analysis	Log Bayes factor (conjugate normal prior; uniform prior on τ)	9–11	Local maxima ages 9 (p = 0.11) and 10 (p = 0.12)
Dichotomised comparison	Welch t + Cohen's d (≤10 vs > 10)	≤10	t = 12.58, p < 0.0001, d = 0.59
Chi-square	χ2 on injury distribution (≤10 vs > 10)	≤10	χ2 = 1448.86, p < 0.0001, V = 0.505

Eight independent analytical approaches applied to identify an age threshold for the number of lesions. Six of seven methods converge on a transition zone around 9–11 years, supporting the ≤10 vs > 10 dichotomisation. CART = classification and regression tree; GAM = generalised additive model; f′ = first derivative.

Table 2: **Convergence of eight methods for identifying the age cut-off.**

GAM-identified age of maximum decline remained at 10.3 years (Gaussian) and 10.1 years (Poisson and negative binomial)–a clinically negligible difference of 0.2 years. Negative binomial group comparison confirmed that the ≤10 group had 57% more injuries than the >10 group (IRR = 1.57 [1.49, 1.65], p < 0.0001), fully consistent with the Welch t-test effect size (d = 0.59). The ordinal model yielded a proportional OR of 0.935 [0.922, 0.947] per year of age (p < 0.0001), confirming the same monotonic decline. A non-parametric Mann–Whitney U test also confirmed the group difference (p < 0.0001).

This data-driven threshold was corroborated by menarcheal status. Among participants in the >10 group with available menarche data (n = 1271), 99.4% were post-menarcheal at the time of abuse. A clear gradient was observed: 60% post-menarcheal at age 11, 88% at age 12, 97% at age 13, and virtually 100% from age 14 onward. Conversely, the observed menarche distribution indicates that over 98% of the ≤10 group

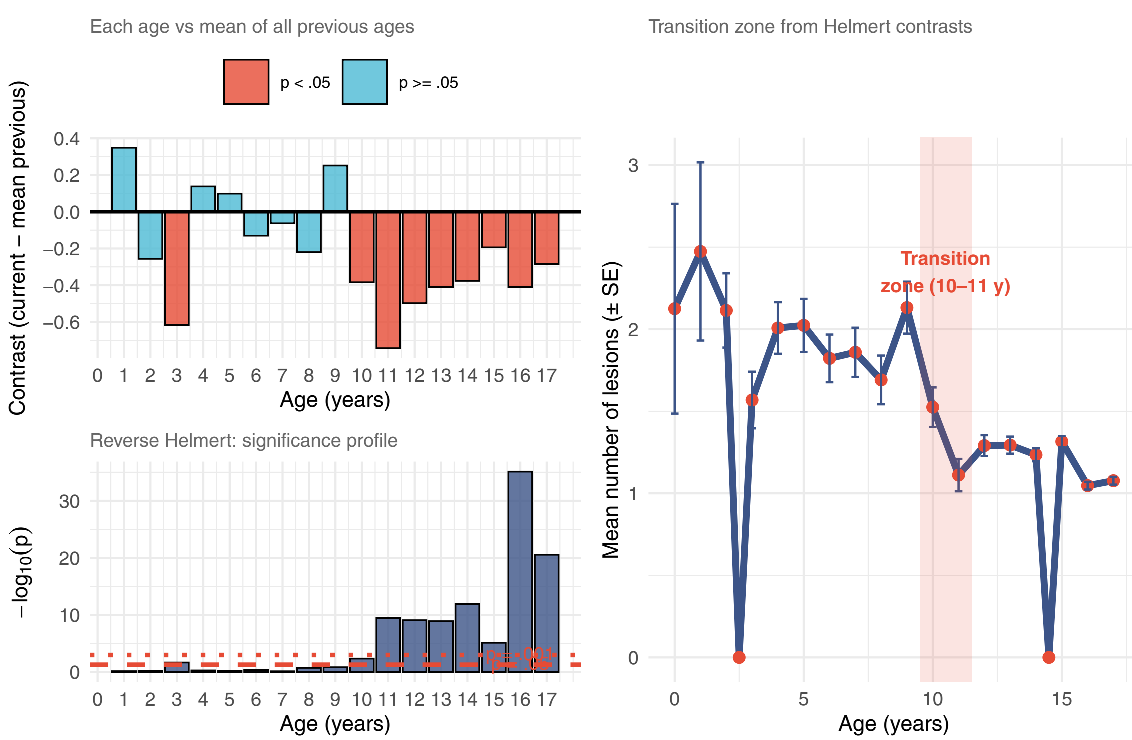

Fig. 3: Reverse Helmert contrasts showing the transition zone for pelvic-perineal injury count by age.

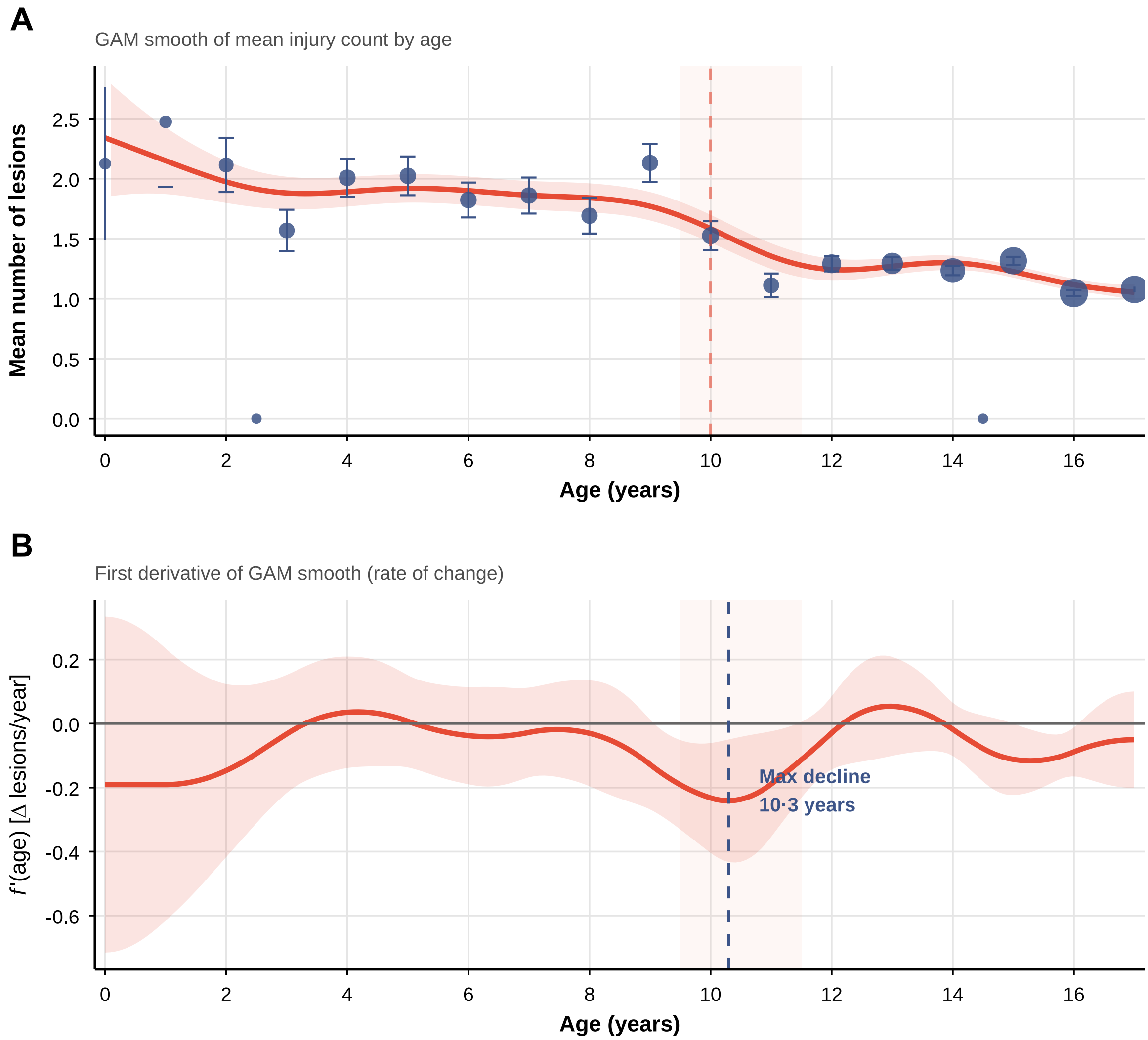

Fig. 4: Generalized additive model (GAM) smooth of mean injury count by age (under 18 years) (A), and first derivative of the GAM smooth showing the rate of change (Δ injuries per year) (B).

would have been pre-menarcheal. Thus, the ≤10/>10 classification closely approximates a pre-/post-pubertal partition, providing biological validation for the statistically derived cutoff.

All injury types except vaginal were significantly more prevalent in the ≤10 group (Table 3). The strongest associations were for hymeneal, anal, perineal, and rectal injuries (exclusive to ≤10). Douglas pouch

Lesion	Prevalence				Cramér's V
	≤10	>10	OR [95% CI]	p	
Hymeneal	56.8%	40.6%	1.93 [1.69, 2.20]	<0.0001	0.130
Vaginal	41.1%	50.4%	0.69 [0.60, 0.79]	<0.0001	0.074
Douglas	1.3%	0.1%	20.64 [5.82, 111.64]	<0.0001	0.090
Perineal	47.1%	22.4%	3.09 [2.69, 3.54]	<0.0001	0.221
Anal	33.2%	4.4%	10.69 [8.86, 12.89]	<0.0001	0.379
Rectal	5.7%	0%	Inf [72.73, Inf]	<0.0001	0.215

Prevalence: Chi-square or Fisher exact test (where expected cell count < 5); OR = odds ratio (≤10 vs > 10); OR > 1 = higher odds in ≤10 group. Cramér's V: < 0.10 negligible, 0.10–0.29 small, 0.30–0.49 medium, ≥ 0.50 large. Rectal OR: complete separation (zero events in >10 group); reported from Fisher exact test. All p values Benjamini–Hochberg corrected; all remain < 0.0001.

Table 3: **Lesion-by-lesion comparison between age groups (≤10 vs > 10 years, N = 5692).**

injuries, though rare (n = 18), were concentrated in younger children. Vaginal injuries were more common in the >10 group.

Network analysis of injuries

Network estimation

Separate Ising models were estimated for the ≤10 and >10 groups (Fig. 5). The ≤10 network retained 9/15 edges (density 60.0%, global strength 27.11), all positive. The >10 network was sparser (5/15 edges, density 33.3%, global strength 17.71) and contained three negative edges; Douglas and Rectal were completely disconnected, consistent with their near-zero prevalence after age 10. As can be seen in Table 4 (left colums), the strongest edge in both networks was Vaginal–Anal (8.57 and 7.80), the most age-invariant conditional association. The largest between-group difference was Perineal–Anal, which reversed from +2.82 in the ≤10 network to −6.16 in the >10 network. Hymenal–Vaginal also reversed sign (+0.73 to −0.18). Douglas–Rectal and Anal–Rectal shifted from 5.60 and 5.16 in the ≤10 network, respectively, to both strictly 0.00 in the >10 one.

Centrality

Anal was the central hub in the ≤10 network (EI = +16.92), followed by Vaginal (+12.36) and Rectal (+11.22), identifying Anal as the central hub through which injury propagation was most likely to occur (Table 5, middle columns). In the >10 network, the hub shifted to Vaginal (EI = +10.79), while Anal dropped to near-neutral (+1.24) and Perineal became the only node with clear negative EI (−2.99).

Stability

Non-parametric bootstrap confirmed that the five strongest edges in each network had 95% CIs excluding zero. Case-dropping bootstrap yielded CS-coefficients of 0.75 for both Strength and EI in both networks, well above the 0.50 threshold for good stability. Betweenness and Closeness were unstable in the >10 network (CS = 0.21 and 0.00, respectively), reflecting its sparse topology; interpretation was accordingly restricted to Strength and EI.

Phi coefficients and co-occurrence

All 15 φ-coefficient pairs differed significantly between groups (Fisher z-test, all $p < 0.05$; Table 4). The Perineal–Anal pair showed the largest shift (z = 31.43, Δφ = +0.848), consistent with its dominant Ising edge difference (ΔW = +8.98). The Hymenal–Vaginal pair was detected by NCT as significantly different (p = 0.0015): both the Ising weight (≤10: +0.73; >10: −0.18) and the bivariate φ (≤10:+0.373; >10:−0.058) reversed sign, indicating that hymenal and vaginal injuries shift from co-occurrence to mild avoidance once other injuries are conditioned upon in the older group. Eight of 15 lesion pairs co-occurred exclusively in the ≤10 group (Table 4). The most striking was Perineal–Anal (32.8% vs 0.0%). All five Rectal pairs were exclusive to the ≤10 group (1.3–5.7% vs 0.0%). Among pairs present in both groups, the

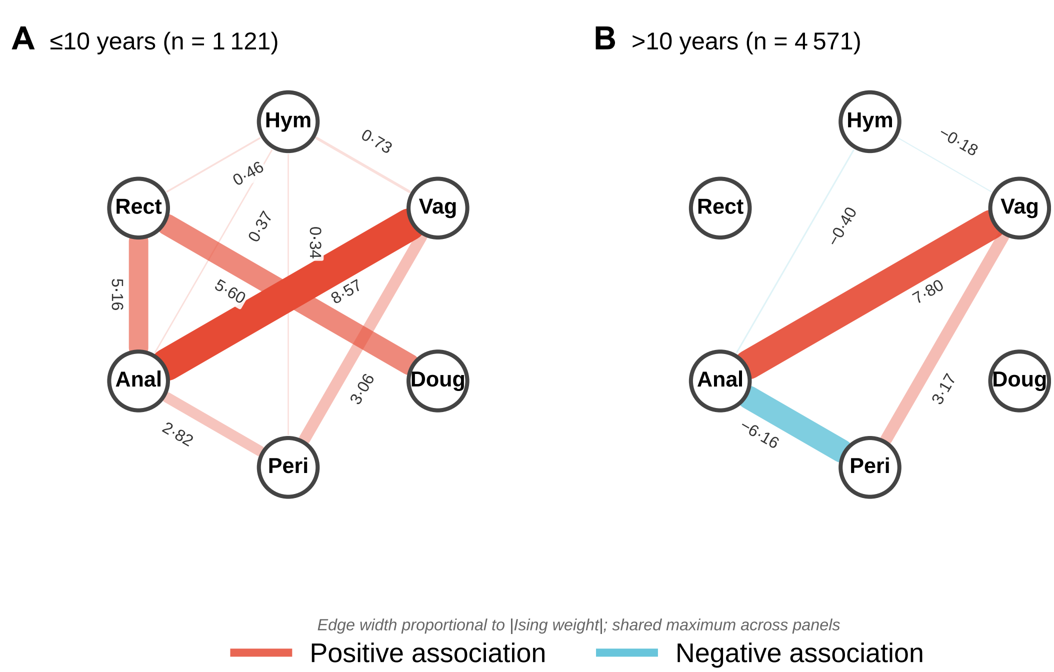

Fig. 5: Ising network models of pelvic-perineal injury co-occurrence in children aged ≤ 10 years (A) and over 10 years (B).

Edge	Ising ≤10	Ising >10	Δ Ising	φ ≤ 10	φ > 10	Δφ	Fisher z p	Co-occ ≤10 (%)	Co-occ >10 (%)	NCT p (BH)
Perineal–Anal	+2.82	−6.16	+8.98	0.732	−0.116	+0.848	<0.0001	32.8	0.0	0.0015
Douglas pouch–Rectal	+5.60	0.00	+5.60	0.473	0.000	+0.473	<0.0001	1.3	0.0	>0.05
Anal–Rectal	+5.16	0.00	+5.16	0.349	0.000	+0.349	<0.0001	5.7	0.0	>0.05
Hymenal–Vaginal	+0.73	−0.18	+0.91	0.373	−0.058	+0.431	<0.0001	32.5	19.0	0.0015
Vaginal–Anal	+8.57	+7.80	+0.77	0.843	0.214	+0.629	<0.0001	33.2	4.4	>0.05
Hymenal–Anal	+0.37	−0.40	+0.77	0.358	−0.053	+0.411	<0.0001	27.2	1.3	>0.05
Hymenal–Rectal	+0.46	0.00	+0.46	0.176	0.000	+0.176	<0.0001	5.3	0.0	>0.05
Hymenal–Perineal	+0.34	0.00	+0.34	0.343	−0.022	+0.365	<0.0001	35.2	8.6	>0.05
Vaginal–Rectal	0.00	0.00	0.00	0.294	0.000	+0.294	<0.0001	5.7	0.0	>0.05
Vaginal–Perineal	+3.06	+3.17	−0.12	0.802	0.456	+0.346	<0.0001	39.1	20.8	>0.05
Douglas pouch–Perineal	0.00	0.00	0.00	0.123	0.007	+0.116	<0.001	1.3	0.0	>0.05
Douglas pouch–Anal	0.00	0.00	0.00	0.165	0.036	+0.129	<0.0001	1.3	0.0	>0.05
Vaginal–Douglas pouch	0.00	0.00	0.00	0.139	0.025	+0.114	<0.001	1.3	0.1	>0.05
Hymenal–Douglas pouch	0.00	0.00	0.00	0.102	0.031	+0.071	0.034	1.3	0.1	>0.05
Perineal–Rectal	0.00	0.00	0.00	0.261	0.000	+0.261	<0.0001	5.7	0.0	>0.05

Sorted by |Δ Ising| descending. Ising = conditional association (eLasso-regularised); φ = bivariate phi correlation; Co-occ = observed co-occurrence rate; NCT p = Network. Comparison Test edge-specific p-value (Benjamini–Hochberg corrected, 5000 permutations). Bold NCT p-values indicate significance at α = 0.05.

***Table 4:* Integrated edge comparison across network, correlation, and co-occurrence analyses.**

largest co-occurrence differences were Hymenal–Anal (OR = 29.1; 27.2% vs 1.3%) and Vaginal–Anal (OR = 10.7; 33.2% vs 4.4%).

Network Comparison Test

Network Comparison Test confirmed that the two networks differed significantly in structure (maximum edge difference = 8.98, p = 0.04), but not in global connectivity (observed difference = 9.39, p = 0.63) (Fig. 5). This indicates that the total amount of inter-lesion association is comparable across groups, yet its distribution across specific edges differs qualitatively. Edge-specific tests (Table 4, last column) identified two significantly different edges: Perineal–Anal (edge difference = 8.98) and Hymenal–Vaginal (edge difference = 0.91). The Perineal–Anal difference alone accounted for the maximum test statistic driving the structural invariance result. Centrality invariance (Table 5, left columns) testing showed no differences in Strength (all p ∼ 0.70) but significant differences in EI for Anal (p = 0.0024) and Perineal (p = 0.024), consistent with their hub shift and sign reversal respectively (Table 5, right columns).

Sensitivity analysis — OR-rule

All key findings were robust to the OR-rule: the Perineal–Anal sign reversal was numerically identical (+2.82 → −6.16), hub identification was consistent (Anal in ≤10, Vaginal in >10), and network density remained higher in the ≤10 group under both rules (AND: 9 vs 5; OR: 9 vs 8). The only difference was three additional Douglas edges recovered in the >10 OR-rule network, suppressed under the more conservative AND-rule.

Discussion

Main findings

This study provides a comprehensive analysis of clinical findings from a large cohort, who received treatment for sexual assault at a specialized sexual violence center

Node	Strength ≤10 (*CS = 0.750*)	Strength >10 (*CS = 0.750*)	EI ≤10 (*CS = 0.750*)	EI >10 (*CS = 0.750*)	NCT p (EI)
Anal	+1.45	+1.31	+16.92	+1.24	**0.0024**
Vaginal	+0.61	+0.81	+12.36	+10.79	0.70
Rectal	+0.40	−0.91	+11.22	0.00	0.70
Perineal	−0.52	+0.53	+6.21	−2.99	**0.024**
Douglas	−0.63	−0.91	+5.60	0.00	0.70
Hymenal	−1.31	−0.82	+1.90	−0.58	0.47

EI = Expected Influence (raw, sum of signed edge weights). Strength = sum of absolute edge weights (z-scored). NCT p = Network Comparison Test centrality invariance p-value (5000 permutations). Bold p-values indicate significance at α = 0.05. CS = centrality stability coefficient (case-dropping bootstrap, 1000 iterations); values ≥0.50 indicate good stability.

***Table 5:* Centrality indices and stability.**

in a region experiencing ongoing armed conflict. Our investigation revealed that the presence, type, and severity of injuries varied with age, with a substantial transition in the injury profile occurring at 10 years. Specifically, the anus was the primary injury hub before puberty (<10 years), whereas the vagina was the most connected hub in adolescents (≥10 years). Moreover, pelvic-perineal injuries observed after abuse were interconnected with the primary sites, reflecting distinct injury networks across age groups.

Key findings

1. Age-dependent injury patterns: the 10-year threshold

This study yielded three principal findings. First, eight independent analytical methods, including segmented regression, CART, sensitivity analysis, reverse Helmert contrasts, GAM, Welch t-test, Bayesian analysis, and chi-square, converged on the 9–11-year range as a critical transition zone for pelvic-perineal injury profiles, with age 10 adopted as the inflection point. This threshold was biologically validated using menarche data: over 98% of the ≤10 cohort was estimated to be pre-menarcheal, while 99.4% of the >10 group with available data had reached menarche.

Notably, the prevalence and severity of injuries decreased with increasing age. The injury burden was substantially greater in prepubertal cases (mean 1.85 vs 1.18 injuries; d = 0.59), with 4–6 concurrent injury sites almost exclusively in the ≤10 years population (χ^2 = 1448.86, V = 0.505). In contrast to vaginal injuries, which predominated thereafter, hymenal, perineal, anal, rectal, and Douglas pouch injuries were significantly more prevalent below the age of 10 years highlighting the specific vulnerability of this age group to serious, complex, and life-threatening injuries.[26]

This finding represents a critical contribution to understanding injury profiles. The 10-year transition point corresponds to pubertal, anatomical, and physiological changes. In prepubescent females, a narrow pelvis and small, inelastic vaginal opening increase vulnerability to severe injury. After puberty, pelvic development, estrogenic effects, and a thicker, more elastic hymen provide greater tissue resilience and reduce injury severity during penetration.[7,27,28]

The availability of menarche data for a subset of participants (n = 1271) provided direct biological validation for this threshold. The median age at menarche in our cohort was 13 years (IQR 12–14), consistent with the reported values for the DRC.[29] Critically, over 98% of the ≤10 cohort were estimated to be pre-menarcheal based on the observed menarche distribution, while 99.4% of the >10 population with available data had reached menarche before the assault. This confirms that the 10-year cutoff effectively captures the pre-and post-pubertal transition. The small number of discordant cases (8 participants aged 11–16 who were pre-menarcheal at the time of abuse) underscores that age and pubertal status are closely but not perfectly aligned, and that individual variation in pubertal timing introduces a narrow zone of overlap in the 10–12 year range, consistent with the 9–11 year transition zone identified by our convergence analysis.

Compared with literature, this finding contrasts with several prior studies that reported a higher prevalence of injuries in adolescents. However, our results align with a minority of studies that also found higher prevalence and severity among young children.[2,14] Discrepancies may stem from differences in age distribution, with small sample sizes of preadolescents and time-lapse to assessment, favoring the absence of injuries following rapid healing of superficial injuries.[9] However, specific and extensive injuries resulting from extreme violence often persist despite delays in care and therefore require special attention,[1,21,30,31] as seen in DRC. In this context, a classification system was developed to describe gender-specific genitourinary and rectovaginal trauma in ≤5 girls in conflict settings, documenting a spectrum of pelvic and perineal trauma (urinary, vaginal, anorectal, and pelvic).[15] The severity of these injuries is comparable to that observed in major accidental trauma.[28]

2. Anatomical primary site: age-dependent injury centrality.

Network analysis revealed qualitatively distinct injury architecture. In prepubertal cases, the anus functioned as the central hub (EI = +16.92), with injury propagation extending to rectal and Douglas pouch structures. In adolescents, the centrality shifted to vaginal injuries (EI = +10.79), with a sparser and more restricted network. The perineal–anal edge reversed from strongly positive (+2.82) to strongly negative (−6.16), which was the single largest between-group difference, confirmed by both AND- and OR-rule estimations.

While this pattern is consistent with clinical hypotheses about the anatomical sites of central hub injuries, we emphasize that network centrality reflects profiles of co-occurrence rather than a proven temporal sequence. The centrality of anal injuries in younger children indicates that they are statistically the most connected nodes, co-occurring frequently with other injury types. The anatomical basis for this pattern is multifactorial. In younger children, the narrow vaginal opening makes anal penetration more accessible to perpetrators and more likely to result in injury. Conversely, post-pubertal anatomical development including pelvic widening, increased vaginal elasticity from estrogen and relaxin, and hymenal thickening makes vaginal penetration more common, while paradoxically reducing injury severity.[28]

From a forensic perspective, identifying the principal site of injuries is essential for establishing legal evidence, identifying assault characteristics, understanding injury mechanisms, and directing appropriate medical care.[32,33] This precision in identifying age-related injury patterns has direct implications for advocacy and compensation for harm suffered.

Our findings are consistent with previous research, indicating that abusive characteristics of injuries are developmentally specific and predominantly localized to the posterior hymen and introitus. Enyedy et al.[34] observed that prepubertal injuries more frequently involved the vestibular and anal regions rather than the vagina itself. Furthermore, our data support the age-dependent laceration patterns identified by McCann et al.,[35] wherein posterior midline lacerations are more common in pre-menarcheal patients and lateral hymenal lacerations in teenagers.

3. Interconnection of injuries to the pelvic and perineal region.

The application of network analysis provides a novel perspective on how pelvic-perineal injuries cluster in cases of child and adolescent sexual assault. Beyond identifying primary anatomical entry-points, this approach revealed stable, age-dependent patterns of co-occurring injuries. Two distinct patterns emerged. In adolescents, perineal and anal injuries showed both direct and indirect positive associations through vaginal injuries (sparsity = 0.67), indicating that vaginal trauma functions as a central mediating node in this age group.

Before puberty, strong linkages were observed between anal and rectal injuries and between rectal and pouch of Douglas injuries. Although hymenal (59%), perineal (48%), and vaginal (42%) injuries were relatively common, they remained secondary to anal injuries (60%, sparsity = 0.40), confirming the anus as the primary anatomical-point in this age cohort.

Understanding these interconnection patterns enables clinicians to anticipate associated trauma and improve diagnostic accuracy.[28,36]

Implications for clinical practice and policy

Understanding age-dependent injury patterns has important clinical and forensic implications. Although our findings primarily reflect conflict-related sexual violence, the observation of an age-related transition in injury profiles at puberty may inform clinical assessments across various settings. These implications are particularly urgent for practitioners working in conflict areas and regions of geopolitical instability, where such severe injuries are more prevalent. In pre-menarchal cases (<10 years), systematic anal and rectal region examinations are essential in contexts where severe, weaponized violence is suspected, as injuries in this age group often involve these sites and may require surgical intervention.[2] In adolescents, vaginal examination should be prioritized. Although these age-specific examination priorities may be less pronounced in non-conflict settings, where the force of assault is typically lower, the principle of developmentally appropriate assessment remains valid in cases of extreme brutality.

These assessments are technically challenging and demand rigorous, age-appropriate clinical practice.[26,28,36] A thorough medical history, examination, and documentation are central to accurate injury assessment.[11,37] This study highlights the need for standardized training focused on pediatric anatomy, the distribution of injuries, and evidence documentation to improve injury interpretation.[2]

Enhanced clinical and forensic assessments[33] also require prompt referral to specialists when internal injuries are suspected.[14,38] Clear referral pathways ensure timely access to medical care, psychological support, and legal services.[38,39] Genital injuries can provide critical forensic evidence, establishing sexual contact, demonstrating force, and corroborating victims' accounts.[40] Age-related injury patterns support reconstruction of assault characteristics and inform legal proceedings and compensation claims. However, absence of visible trauma does not rule out abuse.[2] Sexual violence in children and teenagers can lead to long-term health consequences, including gynecological morbidity, incontinence, and psychological trauma.[37] Accurate medicolegal evaluation is therefore essential both for clinical management and for supporting survivors' access to justice.[28,41]

Limitations and strength

This study has several limitations. First, it was a retrospective, single-center study from one hospital in Eastern DRC, which limits the generalizability of the results to other populations. Second, the sample over-represented older adolescents, with few survivors under 5 years, restricting analysis of injury patterns in young children. Third, substantial data loss during archival transitions led to the exclusion of many potential cases, possibly introducing selection bias. Fourth, age at menarche was available for only 22.3% of participants and was largely restricted to older adolescents (median age at examination 16 years), precluding direct analyses of injury patterns stratified by pubertal status. However, the observed menarche distribution allowed us to confirm that the ≤10/>10 age cutoff closely approximates a pre-/post-pubertal classification, despite potential influences such as malnutrition and stress, and this concordance should be considered when interpreting age-specific findings. Fifth, several clinically relevant covariates were not incorporated into the regression or network models. The time to presentation (≤72 h vs later) was described descriptively but not modeled. Assault characteristics, such as the number of perpetrators or use of objects, were not consistently recorded as structured variables across the full retrospective dataset spanning 2003–2020. The distinction between chronic and acute injuries was also not systematically coded as a separate variable, which prevented us from adjusting for these factors in the analysis. Consequently, covariate-adjusted models could not be fitted for the full sample. In our analysis, all forms of sexual abuse were explicitly considered without distinction, encompassing vulvar touching, penile penetration, and the insertion of objects into the genitalia or anus. This approach was adopted to comprehensively capture the full spectrum of weaponized sexual violence in conflict settings.

Despite these limitations, the strengths of this study are notable: a large dataset enabling robust statistical analysis, analytical precision in injury classification, determination of the 10-year inflection point without a priori assumptions, and the first application of network modeling to anogenital lesions following sexual abuse. These observations were possible due to Eastern region of DRC context, early care consultations, and complex injuries treated at PH by a multidisciplinary team.[3,42–44]

Several methodological features strengthen the reliability of our network findings. First, the centrality stability coefficient of 0.75 for strength and EI in both age groups exceeded the recommended threshold of 0.50 by a substantial margin, indicating that centrality rankings and the identification of anal trauma as the prepubertal hub and vaginal injuries as the adolescent hub are robust to sample perturbation. Second, a sensitivity analysis using the OR-rule for edge selection replicated all key findings, including the sign reversal of the perineal–anal edge and the shift in hub identity across age populations. This convergence across estimation rules mitigates concerns about the arbitrariness of the AND/OR decision in Ising network estimation, a methodological choice that has been flagged as potentially influential in applied network studies.

Conclusion

This study identifies age 10 as a key threshold at which the presence and severity of sexual abuse-related injuries shift, with injuries more frequent and severe in younger cases. This pattern underscores the anatomical and physiological developmental changes as important mitigating factors. A second major finding is the age-dependent variation in injury core within pelvic-perineal trauma networks: anal injuries predominated central hub lesions in those under 10 years, whereas vaginal injuries were central among those aged 10 years and older. These age-related patterns highlight the need for clinicians to consider pubertal status when conducting examinations, interpreting findings, and addressing forensic implications. Recognition of these distinctions is essential for guiding acute management, as well as long-term follow-up of pediatric sexual abuse survivors. Further research is necessary to evaluate the long-term impact of lesions and reconstructive care on quality of life, sexual health, pelvic floor function, and body image across these distinct developmental stages.

Contributors

RM, FG, AB, BD, and DM were responsible for the research design; RM and AB recruited participants and led data collection; BD and RM performed the main analysis with additional contributions from other co-authors. RM, DM, AB, FG, and BD accessed and verified the underlying data reported in the paper. RM, BD, and DM wrote the first version of the manuscript; RM, FG, AB, JM, BD, AM, LK and DM critically revised the manuscript for important intellectual content. All authors had full access to all data in the study and took final responsibility for the decision to submit the manuscript for publication. They contributed to the revisions and approved the final manuscript. They also attest that they meet the ICMJE criteria for authorship.

Data sharing statement

De-identified individual participant data, the data dictionary, and statistical code used in this study can be made available by request to the corresponding author by email. For some requests, access may require submission of a protocol, approval by the principal investigators, and the signing of a data access agreement.

Declaration of interests

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanafr.2026.100079.

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