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Wound Care in Nonhuman Species: An Integrated Framework Applied to Central African Chimpanzees

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ABSTRACT

Wound care represents a major challenge across species, with impaired wound healing imposing substantial costs on health, survival, and fitness. Insights from nonhuman animals offer promising avenues for understanding wound-management strategies and identifying novel therapeutic compounds. Yet, despite the strong consequences of wound healing for survival and fitness—especially in free-living populations—wound-management strategies remain poorly understood. A key limitation is that existing methods for evaluating wound characteristics rely on close-range observations, leaving a substantial gap for species that cannot be observed up close. As a result, the diversity of wound-tending behaviors and their relationship to wound condition and healing remain little understood. We introduce a novel methodological framework and demonstrate its application to Central African chimpanzees (*Pan troglodytes troglodytes*) living in the wild. The framework merges two complementary components: (1) a systematic classification of wound-tending behaviors in nonhuman species by establishing a standardized ethogram; and (2) a structured, distance-based assessment of wound impact, based on multiple observable characteristics. By combining a systematic behavioral classification with a distance-based scoring system, the framework overcomes key limitations of existing approaches. The proposed method is flexible, feasible, and transferable across species, facilitating systematic comparative research on health-related behaviors.

1 | Introduction

Throughout our evolutionary history, the development of medical knowledge has been one of the most influential factors in human survival [1–4], to the extent that it has been described as "the greatest benefit to mankind" [5, 6]. The earliest evidence of medicinal knowledge in hominins stems from the remains of a Neanderthal (*Homo neanderthalensis*) found in the El Sidrón Cave in northern Spain, whose dental calculus showed fragments of bitter-tasting plants with no nutritional value—yarrow (*Achillea millefolium*)and chamomile (*Matricaria chamomilla*) [7]. These plants are well known for their medicinal properties, acting as astringents [8] and for counteracting gastrointestinal disorders [9]. In addition, the equipment of the best-preserved prehistoric human skeleton ever found, the Tyrolean Iceman, suggested that he used a moss (*Sphagnum imbricatum)* with absorbent and antiseptic properties to treat a hand wound [10]. More broadly, recent research interest in understanding, treating, and preventing diseases has increased substantially over the last decades. Within this continually expanding field, wound care represents a crucial domain due to the recurrent emergence of life-threatening complications and the substantial economic burden it imposes [11, 12]. It is defined as the management of wounds that affect skin and underlying tissues [13]. Every year, millions

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of people experience disability associated with skin ulcers [14, 15], with prevalence rising among aging populations [16, 17], and particularly in individuals affected by chronic conditions (such as diabetes, obesity, and peripheral vascular disease) [17, 18]. Reflecting this widespread but under-recognized impact, wound burden has also been described as a silent epidemic [14, 19]. Due to the substantial impact of wound healing on individuals' lives and survival [20], considerable progress has been made concerning wound assessments [21]. For instance, standardized approaches have been developed to enhance the evaluation of healing trajectories and treatment responses by providing patient-centered evaluation of critically relevant wound features [22–24]. One example is the Photographic Wound Assessment Tool (PWAT) [22, 25], which translates specific target wound characteristics, such as wound size, depth, the presence and amount of necrotic tissue, and edge condition, into a standardized numeric scoring system for healing trajectories over time. However, despite ongoing improvements in assessment tools, broader inconsistencies in wound care practices remain unresolved, as standardization alone has not addressed lasting challenges in early intervention and resource optimization [14, 26]. These limitations emphasize an increasing need for complementary or alternative approaches to optimize healing trajectories and make more efficient use of available resources [27].

Beyond the clinical and systemic constraints that shape human wound care, injury itself represents a fundamental biological phenomenon shared across species: Nonhuman animals regularly sustain wounds and employ different behavioral strategies to mitigate their impact [28]. While the role of these behaviors in wound healing processes remains an understudied domain, research on animal medication has gained increased attention in recent years [29, 44, 70]. In this context, behavioral responses to injury can be understood as part of a broader spectrum of medicative strategies, although their contribution to healing remains an understudied source of insight [28]. Today, animal medication is defined as the set of behavioral strategies adopted by nonhuman animals to prevent, mitigate, and treat diseases through the use of plants, animals, or inorganic substances [29]. Evidence of such behaviors has expanded across a broad range of taxa, including mammals [30–32], birds [33–36], amphibians [37, 38], reptiles [38–40], and numerous invertebrate species [41–43]. Among topical strategies—behaviors directed toward skin infections, ectoparasites, or injuries [29, 44–46]—wound-related medication remains comparatively rare [47], and is mostly documented as isolated cases: in insects such as ants (*Camponotus floridanus* [48]), in reptiles such as snakes [39] and lizards (*Calotes versicolor* [38]), in birds such as woodcocks (*Scolopax minor* [33]); in mammals including black bears (*Ursus americanus*), muskrats (*Ondatra zibethicus*), beavers (*Castor canadensis*), raccoons (*Procyon lotor*) [33], deer (*Cervus elaphus* [49]), elephants (*Loxodonta africana* [50] and *Elephas maximus* [51]), capuchin monkeys (*Cebus apella* [52, 53]), mountain gorillas (*Gorilla beringei beringei* [47, 54]), orangutans (*Pongo abelii* [55]) and Central African and Eastern African chimpanzees (*Pan troglodytes troglodytes* [56] and *Pan troglodytes schweinfurthii* [57], respectively). As in humans, wound-tending behaviors—here defined as actions directed toward inspecting, cleaning, or managing wounds—have received considerably less attention than the study of other healthcare strategies, with available information largely being anecdotal or limited to sparse observations. Reported behaviors range from wound licking (bisons [58], mice [59], and chimpanzees [60]) to the application of leaves (chimpanzees [4, 61–69]), chewed plant material (orangutans [55]), or other substances (beavers, muskrats, and bears [33]; deers [49]; capuchin monkeys [53, 70]; elephants [71]), and include even targeted amputations, a behavior so far documented only in two taxonomically distant species (racoons: *Procyon lotor* [33], and ants: *Camponotus floridanus* [48]). Yet, with few exceptions involving systematic investigations (e.g., in ants [48] and chimpanzees [67]), these behaviors have generally been documented through sparse, rare observations and limited sample sizes. Consequently, wound-tending behaviors have never been integrated into a unified and species-specific analytical framework that could provide a standardized basis for investigating their diversity and occurrence, as well as the cognitive processes underlying wound-caring strategies.

Similarly, despite a growing body of literature on animal health, wound assessment in nonhuman species remains constrained by factors such as observational distance and ethical considerations [72]. As a result, for domestic and captive species, the evaluation of healing trajectories has relied on standardized approaches, such as the TIME framework [73], or on metrics often limited to wound presence [74–75] or severity classes [74, 76–78]. In nonhuman primates, for example, wound severity has commonly been quantified using the 5-point scale first developed by Ross and colleagues [78], which, although robust across different research contexts such as categorization of wounding events and management of individuals within facilities, is less sensitive to temporal variation and the subtle changes during healing. Consequently, in wild populations, current approaches often fail to capture the dynamic nature of wound healing and wound-tending behaviors associated with it.

Hence, the aim of the present paper was two-fold. First, we aimed to address the lack of systematic, standardized approaches in nonhuman wound behavior research [47, 73] and to facilitate systematic assessments of wound conditions across taxonomic groups by proposing an analytical framework that integrates behavioral observations with a quantitative assessment of wound impact (WI), thereby enabling, for the first time, a systematic examination of how variation in wound condition shapes wound-tending behaviors. Second, we demonstrated its application to the study of wounds and wound-tending behaviors in one of our closest living relatives, the chimpanzee (*Pan troglodytes*), a unique model system that mirrors many of the social dynamics found in humans [79–81].

To do so, we collected behavioral data on a group of Central African chimpanzees living in the Loango National Park in Gabon, with a special focus on physical characteristics of wounds and the wound-care behaviors directed toward them. To overcome distance-based observational limitations while maintaining a clinically informed methodological approach, the proposed framework combines clinical approaches to wound assessment in both human [25] and nonhuman species [73, 82] and relies on evaluating characteristics that do not necessarily require close-up inspection or dimensional measurements. Within this context, the framework aims to analyze wound-tending behaviors as graded responses rather than isolated acts by integrating two components: (1) a multidimensional, distance-based assessment

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of WI based on observable characteristics (e.g., severity, mobility, surface status, and edge condition), and (2) a standardized classification of wound-tending behaviors. In doing this, this study seeks to facilitate future research on wound healing and wound-tending behaviors and comparative insights that may ultimately advance our understanding of wound management in humans.

2 | Materials and Methods

2.1 | Study Site and Data Collection

Data were collected on the behavior of individuals of the Rekambo community living in the Loango National Park, Gabon (2° 04′ S and 9° 33′ E). The park consists of a mosaic of different habitat types, including coastal forests, savannahs, lowland swamps, and primary tropical rainforest [83, 84]. Habituation of the group began in 2005, and most of the adult males were habituated to the presence of human observers by 2017. Following a 7-month pilot study, behavioral observations were conducted over 24 months, from July 2022 to July 2024. During this time, the community consisted of 37 individuals: 17 adult chimpanzees (eight males, nine females), six subadult females, two adolescents (one male, one female), two juveniles (one male, one female), and 10 infants (five males, five females) (age class was attributed following Goodall's 1968 classification [85]).

Upon finding the chimpanzees in the early morning, we followed them for the rest of the day using all-day focal animal sampling [86]. To ensure that behavioral responses to injuries could be characterized across healing trajectories, focal subjects were observed for multiple days until complete recovery. The selection criteria for the focal animals were based on wound frequency, habituation to human observers, and an attempt to evenly represent sex and age classes. Of the 37 individuals, nine males and nine females were selected as focal subjects for this study. Overall, these 18 focal individuals were followed for 347 days. Males were observed for a cumulative 1869 h (mean per male: 208 h; SD: 63.7), while females were observed for 1107 h (mean per females: 123 h; SD: 47.7). Data were collected using a data collection protocol in CyberTracker software (https://cybertracker.org version 3.507), installed on water-resistant smartphones (Cyrus CS45), and by recording behavior with a digital high-definition video camera (SONY 4K AX53). All observations and recordings were conducted at a minimum distance of 8 m to prevent disease transmission from humans and chimpanzees and to avoid disturbing their natural behavior [122, 123].

2.2 | Wounds

Wounds were defined as any disruption of epithelial integrity, including abrasions (epidermal loss), lacerations (dermal tearing), or punctures (penetration of underlying tissue) [87]. Wounds were recorded ad libitum [86] for all visible individuals within the party throughout the day when visibility allowed and tracked across days until recovery. Because multiple wounds could be sustained during a single aggressive event, we distinguished between wound number and wounding events, the latter defined as the occurrence of one or more wounds arising from the same aggressive interaction [88]. Each wound was assigned a wound identifier consisting of the event number and wound number. For example, the labels *wound_6;1* and *wound_6;2* denote wounds 1 and 2, both acquired during the wounding event 6. Wound characteristics were documented using two procedures: first, direct observations with binoculars; and second, coding the video footage and conducting detailed analysis based on screenshots extracted from it. Whenever possible, we collected multiple photographs throughout the day and eventually chose those in which the characteristics of interest were most visible. Overall, we extracted 3669 screenshots from the video material, which were subsequently used to score wound characteristics. For each wound, we recorded the date and time of observation, the identity of the injured individual, and the anatomical location and side of the body.

To allow for different levels of granularity that could support subsequent analyses, wound location was assigned based on a distinction between *body parts* and *body regions*. Body parts referred to specific anatomical structures (e.g., hand, wrist, forearm), whereas body regions referred to broader body segments encompassing one or more body parts. Following the anatomical model described for adult chimpanzees by [89] and [90], we defined nine body regions: (1) head (including neck), (2) upper arm, (3) forearm, (4) hand, (5) thoracic region, (6) abdominal region, (7) thigh, (8) shank, and (9) foot (Figure 1). In contrast to the previous models that grouped the torso into a single region, we separated thoracic and abdominal segments to increase anatomical resolution in areas differing in exposure and accessibility during wound-tending behaviors. To determine wound occurrence while accounting for unequal observation effort inherent to chimpanzee fission–fusion dynamics, we applied the exposure-based standardization approach for variable group composition described by Altmann and Altmann (Case 2 [91]). Wound counts were analyzed using a negative binomial mixed-effects model to accommodate overdispersion in count data. To correct for differences in individual sampling effort, we reconstructed the dataset at the level of observation days per individual, assigning the number of newly detected wounds per day and including zero counts for days without wounds. We fitted an intercept-only model with individual identity as a random effect to derive an estimate of the average wound rate while accounting for repeated observations and variation among individuals.

2.3 | Wound-Tending Behaviors

Wound-tending behaviors were recorded using an ethogram that incorporated both behaviors previously described in the nonhuman animal literature and behaviors identified during a 7-month pilot study. Overall, we identified 27 distinct wound-tending behaviors (Table 1): *apply chewed plant material* [55], *apply composite material* [33], *apply inorganic material* [33, 47, 50, 51, 70, 71], *apply insect* [56, 57], *apply nonplant organic material* [52, 53], *apply saliva* (adapted from [61]), *apply unprocessed plant material* [33, 47], *amputate* [33, 48], *bath in herbal water* [49], *cover* (this study), *dab leaves* [4, 61–65, 67–69], *lick* [54, 59–61, 75, 92–96], *look* (this study), *maintain* (this study), *mouth* (this study), *move hair* (this study), *open* (this study), *peer* (adapted from [97]), *pluck hair* [75], *press* (this study), *remove dead skin* [75, 98], *remove dirt*

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TABLE 1 | Ethogram of wound-tending behaviors reported in nonhuman animals.

Inspect		
Look	Visually examines their own wound for more than 2 s, without engaging in any additional wound-tending behaviors during this interval.	This study
Move hair	Uses body parts (i.e., hands or mouth) to push hair back away from the wound while looking at it.	This study
Pluck hair	Removes hairs surrounding a wound by pulling it out, creating a clearing of the area.	[75]
Open	Applies deliberate pressure with hands or fingers around the wound edges.	This study
Peer	Gazes at another individual's wound from within close proximity.	Adapted from [97]
Smell	Sniffs the wound, or the substrate (hand or leaves) immediately after these have been in contact with the wound.	[63]
Touch	Makes brief, light contact with a wound using a hand or fingers.	[61, 63, 99]
Clean		
Apply saliva	Transfers saliva to the wound, typically involving fingers or hand contact with the wound, followed by licking of the contacted body part, and subsequent saliva deposition onto the wound.	Adapted from [61]
Dab leaves	Applies leaves on the wound surface. Leaves may be manipulated before and/or between applications (e.g., folded, licked, placed in the mouth, visually inspected, or sniffed) before discarding.	[4, 61, 63–68, 124]
Lick	Laps the wound through direct tongue contact.	[54, 59–61, 75, 92–94, 96]
Mouth	Encloses the wound with the lips without visible tongue use, creating rhythmic oral movements against the surface.	This study
Press	Applies pressure or squeezes the wound margins using fingers or hands, sometimes resulting in visible fluid or blood release.	This study
Remove dead skin	Detaches dying/dead skin or wound crusts (e.g., scabs) surrounding the wound using mouth, hands, or teeth.	[75, 98]
Remove dirt	Mechanically clears material from the wound surface using fingers or fingernails, often involving scraping or picking motions. May subsequently lick their fingers.	Adapted from [60, 75]
Remove larvae	Extract visible larvae—typically fly larvae—from the wound surface using fingers, nails, lips, or teeth.	[75]
Prevent		
Cover	Places the palm or fingers over the wound surface, covering it and limiting visible exposure of the wound.	This study
Repel insects	Moves arms or hands in a fast motion in the presence of insects, with visible disappearance of the insects away from the wound surface.	This study
Topical application		
Apply chewed plant material	Chews and manipulates plant material and subsequently applies it to the wound surface.	[55]
Apply unprocessed plant material	Places directly to the wound surface plant derived substances—such as resin, tree gum, moss, and sphagnum—in an unprocessed form.	[33, 47]
Bath in herbal water	Immerse the wound in water dominated by vegetation enriched with bioactive herbs or plant materials—such as moor waters. For this, water needs to be clearly plant-dominated and exclude immersion in mixed-substrate or mineral-dominated waters such as swamps, mud pools, or sediment-rich water.	[49]

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TABLE 1 | (Continued)

	Apply nonplant organic material	Deposits nonvegetal organic substances—such as honey, syrup—on the wound surface.	[52, 53]
	Apply insect	Places one or more insects to the wound surface, typically caught from foliage and immobilized before application using fingers or mouth. Insect parts are usually discarded after application.	[56, 57]
	Apply inorganic material	Deposits inorganic substances—such as clay, mud, dust, mineral-rich sediment—to the wound surface.	[33, 47, 50, 51, 70, 71]
	Apply composite material	Deposits a mixture of organic and inorganic substances—such as clay, plant roots, and grass—to the wound surface.	[33]
Surgical			
	Amputate	Actively removes body parts at or around the wound site by applying sustained force until the tissue is detached.	[33, 48]
Other			
	Maintain	Stabilize the body part where the wound is located using one or two hands.	This study
	Scratch	Draws nails across the skin surrounding or over the wound surface, without visible removal of material from the wound.	This study

Note: The table presents 27 behaviors grouped in six overarching categories according to their primary function in wound management. Definitions marked as "adapted" were modified from their original sources to broaden their scope, while definitions marked as "this study" were operationalized for the purpose of this study.

[60, 75], *remove larvae* [75], *repel insects* (this study), *scratch* (this study), *smell* [63], and *touch* [61, 63, 99]. Notably, the behaviors *press* and *remove dead skin* were first identified during video analyses, while *apply saliva* and *lick*—initially coded together in the field as a single behavior (*lick*)—were later separated to increase behavioral precision and to better capture differences in action structure.

We categorized behaviors into six functional classes—*clean*, *inspect*, *prevent*, *other, surgical*, and *topical application*—to facilitate interpretation and generalization. The category *clean* includes behaviors involving the application of saliva (directly with tongue, hand, fingers, or with external substances such as leaves) as well as the removal of blood, dirt, or debris from the wound bed or edges. The category *inspect* comprises behaviors that improve the wound's visibility, while the category *prevent* includes behaviors that limit external stressors' contact with the wound. The category of *topical application* [29, 44–46] includes medicinal and potentially medicinal behaviors that involve applying organic parts (plant parts or insects), organic substances (e.g., honey or syrup), or nonorganic compounds (e.g., clay or mud) to the wound surface. The category *surgical* includes the behavior *amputate*, documented so far in wild North American raccoons (*Procyon lotor* [33]) and systematically in the ant species *Camponotus floridanus* [48], where it is characterized by the directed removal of body parts around the wound site. Lastly, the other category includes two behaviors—*maintain* and *scratch*—that fall within a broader range of interpretations. Each behavioral event was explicitly linked to a specific wound, allowing behavioral responses to be analyzed with respect to the wound state.

2.4 | Analytical Framework—How to Apply the Framework

The framework follows a sequential structure (Figure 2), progressing from field data collection to inferential output, while remaining modular to accommodate varying levels of data availability.

Step 1. Data collection

The framework begins with observational data, including focal follows [86], video recording, and photographic documentation of wounds. These sources provide complementary information: focal follows ensure continuous monitoring of behavioral activities, including wound-tending behaviors, using a standardized ethogram (Table 1); video recordings allow fine-grained post hoc behavioral coding; and wound photographs enable detailed, repeated assessment of wound characteristics across days.

Step 2. Behavioral data extraction

Wound-tending behavior can be characterized and quantified at two complementary levels: discrete behavioral events (e.g., licking, touching, or applying an insect) and broader functional categories (e.g., cleaning, inspection, or prevention). This hierarchical classification allows the framework to accommodate both high-resolution datasets and settings in which only broader

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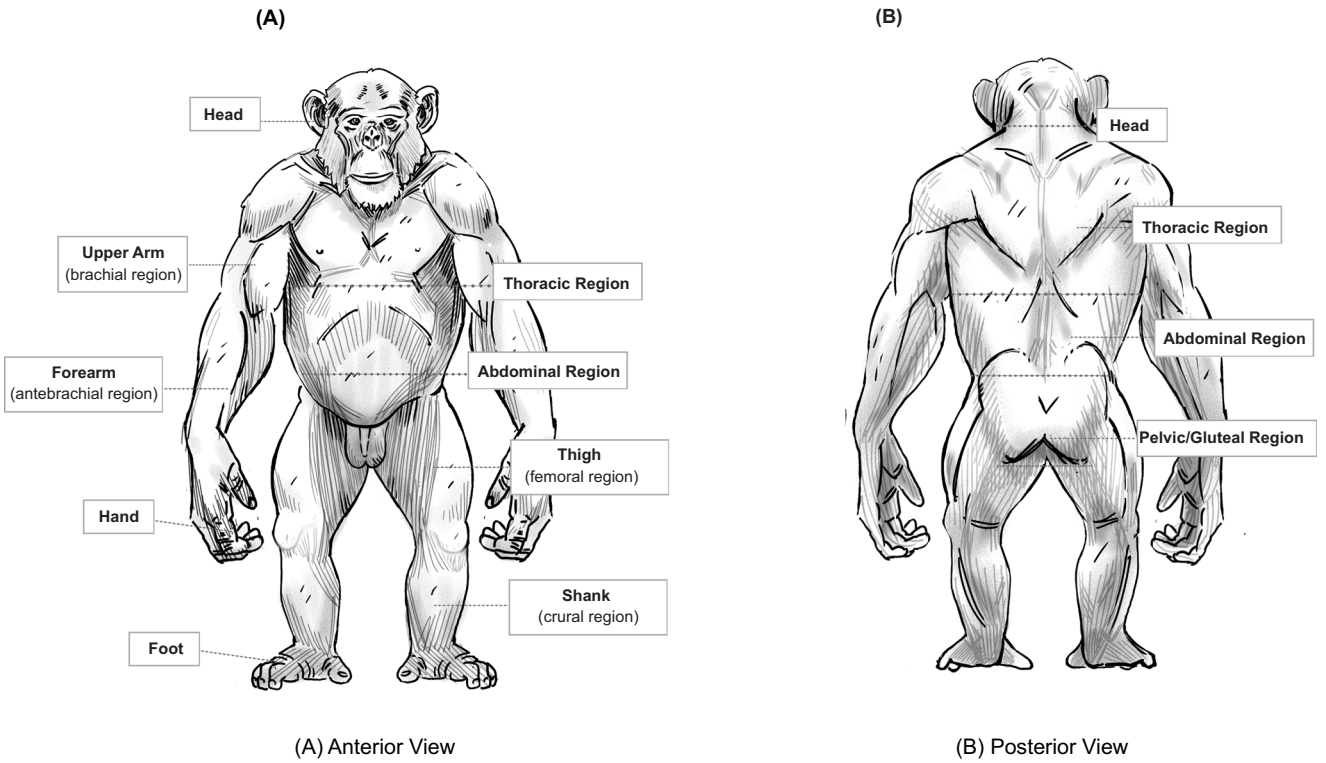

FIGURE 1 | Body regions used for wound location and scoring of WI features. Anterior (A) and posterior (B) views of a standardized chimpanzee body template illustrating the body regions used in this study. Classification is adapted from the anatomical models of Crompton and colleagues [89] and Schoonaert and colleagues [90].

behavioral categories can be reliably identified. It also facilitates comparisons across studies that differ in observational details and record methodologies, while preserving biologically meaningful variation in wound-care strategies.

Step 3. Wound assessment and scoring

From the raw photographic material, WI was assessed using four observable characteristics that can be reliably scored under distance-based conditions, which in our case was approximately 8 m. These characteristics include wound severity, mobility, surface, and edge status (Table 2). Following a multicharacteristic, score-based approach inspired by the clinical PWAT used in human wound assessment [22, 25], we adapted it to noninvasive, field-based settings by systematically evaluating each characteristic independently. This approach represents a key methodological advance compared to previous studies on nonhuman species [74, 76–78], as it allows wound condition to be characterized in a multidimensional manner and tracked over time across healing stages. The assessment can be conducted post hoc from photographic material or directly in the field through visual assessment (e.g., with binoculars). However, we recommend photographic documentation whenever possible to facilitate verification of wound characteristics and inter-rater reliability ([e.g., 100, 101]), as observation distance and variable field conditions may otherwise lead to misclassification.

Step 4. Inferential output

The final and key step of the framework was to link each wound-tending event to a specific wound. This one-to-one linkage moves beyond binary classifications of individuals as wounded or not and allows behavioral responses to be analyzed as a function of the state of a particular wound, as defined by its observable characteristics. By directly relating wound-tending behaviors to variation in wound condition, the framework enables the systematic examination of how specific wound attributes shape behavioral responses.

Step 5. Distance-based WI assessment

To quantify wound condition under distance-based constraints (e.g., observation distance, no manipulation, no clinical measurements), we operationalized WI as a multidimensional profile of observable characteristics that capture tissue damage, mechanical stress, and healing state on normal movement and behavior. This conceptualization is consistent with broader definitions of wound burden and clinical guidance emphasizing that wound assessment should consider multiple wound attributes rather than relying on a single indicator [102]. Building on clinical photographic scoring approaches (e.g., PWAT [25]) and on primate wound severity scoring systems used in behavioral research

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TABLE 2 | Components and scoring criteria of WI characteristics.

Characteristic	Score	Definition	Reference
Severity			
	0	Healed: wound is closed.	Adapted from [78]
	1	Superficial wound: minor skin damage such as abrasions, scratches, or scrapes. No bleeding observed.	
	2	Shallow wound: skin is broken but underlying tissue is not visible. Some bleeding may occur.	
	3	Moderate wound: laceration or puncture with possible tissue exposure. Bleeding and mild swelling may be present, temporary impairment possible. Limited tissue loss may be present, such as the loss of a portion of the ear, but does not involve complete loss of a digit or appendage.	
	4	Deep wound: significant tissue damage with exposure of tissue or bone. Pronounced bleeding, often accompanied by swelling, and reduced use of the affected area.	
	5	Severe wound: extensive damage with exposed tissue or bone, or missing body parts. Heavy bleeding, major swelling, and serious impairment.	
Mobility			
	1	Low (e.g., scalp, immobile body parts). Wound is located on a body part with minimal movement and limited mechanical stress.	This study
	2	Moderate (e.g., thorax, abdomen, vulva). Wound is located on a body part subjected to occasional movement and moderate mechanical stress.	
	3	High (e.g., joints, limbs, mouth, neck). Wound is located on a body part exposed to movement and elevated mechanical stress.	
	4	Extreme (hands, feet, sexual swelling, penis). Wound is located on a body part subjected to continuous movement and intense mechanical stress due to frequent use.	
Surface status			
	0	Healed/nearly healed: wound is closed or nearly closed. Skin continuity is restored or a minimal superficial scab remains. No visible redness, swelling, or discharge.	Adapted from [25]
	1	Clean: wound is open but appears healthy. If present, bright red granulation tissue predominates. No visible dirt, slough, pus, or discoloration.	
	2	Contaminated: wound shows visible dirt, debris, or dried material. Granulation tissue may be pale or patchy. No obvious pus or signs of active infection.	
	3	Infected (localized): visible signs of local infection: increased redness, swelling, or mild discharge. Slough or necrotic tissue may be present. Small amounts of pus may appear.	
	4	Infected (advanced): heavy pus (yellow/green/brown), extensive redness or swelling beyond the wound. Tissue appears discolored, fragile, or breaking down.	

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TABLE 2 | (Continued)

Characteristic	Score	Definition	Reference
Edges			
	0	Closed, nearly closed or edges indistinct, diffuse, not clearly visible because of re-epithelialization.	Adapted from [25]
	1	More than half of the edges are attached, with a visibly advancing epithelial border.	
	2	Most edges are attached to the wound base, without advancing.	
	3	Most edges are unattached and/or undermined.	
	4	Most edges are rolled, thickened, or fibrotic (excluding callus formation).	

Note: Definitions marked as "adapted" were modified from their original sources to accommodate distance-based observational limitations, while definitions marked as "this study" were developed in the present study.

[78], we adapted these tools to wild settings using the evaluation of characteristics that do not necessarily require short-distance inspection and dimensional measures. Specifically, the wound condition was assessed using four characteristics: (1) severity; (2) mobility; (3) surface status; and (4) edge characteristics. Each characteristic was rated on a numerical scale (Table 2), with higher scores indicating more unfavorable wound attributes and, consequently, greater WI. Scores for severity, surface status, and edge condition were recorded longitudinally to capture changes across healing stages. Mobility was treated as a contextual characteristic of the affected body region, reflecting mechanical stress exposure that may affect healing and wound-tending behaviors.

2.5 | Wound Characteristics and Scoring

2.5.1 | Severity

Severity is assessed on a 6-point scale adapted from Ross et al. [78], excluding dimensional references (e.g., depth) that cannot be reliably evaluated at a distance. In this revised form: (0) wound is closed or nearly closed; (1) superficial wounds, with partial breakage of the skin; (2) shallow cut resulting in a complete breakage of the skin, no underlying tissue visible; (3) moderate wound, laceration or puncture with possible tissue exposure; (4) deep wound, with tissue or bone exposed; (5) severe wound, with tissue or bone visible and potential loss of body parts.

2.5.2 | Mobility

Mobility reflects the intrinsic mechanical tension of the corresponding body region and serves as a proxy for the mechanical stress acting on the wound [103–105]. Increased mobility—particularly at joints—can generate tension, friction, and separation of wound edges, potentially interfering with tissue repair [106]. Mobility is scored on a 4-point scale based on the expected mechanical stress of the body part: (1) low, with wound is located on a body part with minimal or no movement (e.g., scalp, head, forehead); (2) moderate, with wound located on body parts exposed to moderate mechanical stress (e.g., thorax, abdomen, vulva); (3) high, with wounds exposed to frequent mechanical stress (e.g., joint, limbs, mouth); and (4) extreme, with wounds subjected to body areas continuously used (such as hands and limbs), or subjected to frequent friction (such as tumescent female genitals or penis).

2.5.3 | Surface status

Surface status, defined as the condition of the wound surface [102], is a critical indicator of healing progress and infection risk. It is scored on a 5-point scale ranging from 0 (healed/nearly healed) to 4 (advanced infections).

2.5.4 | Edges

Edges are defined as the epithelial advancements that directly extend into the wound base. These edges can be attached to the wound base or may be undermined, thickened, or rolled upon themselves. We based the scoring on the PWAT edge criteria [25], omitting dimensional references. Characteristics are scored on a 5-point scale, with attached and advancing epithelial borders receiving lower scores than unattached or undetermined cases (i.e., edges that are poorly defined or cannot be clearly distinguished from the surrounding skin), which receive higher scores.

3 | Results

3.1 | Wound Dataset Overview

Over the 24-month observation period, we documented a total of 550 wounds across 37 individuals, of which 31 individuals presented at least one wound (individual mean: 14.86 ± 15.97 wounds; range = 0–55). In 100 cases, the cause of injury could be reliably determined through direct observation of the event. Of these, 92 wounds resulted from intragroup aggressive interactions, one from an encounter with a neighboring community, two from falls, four from predation attempts on red-capped mangabeys (*Cercocebus toquatus*), and one from tool manipulation.

The intercept-only negative binomial mixed model estimated a mean wound rate of 0.0033 wounds per observation day and individual ($\beta_0 = -3.41$ on the log scale), corresponding to

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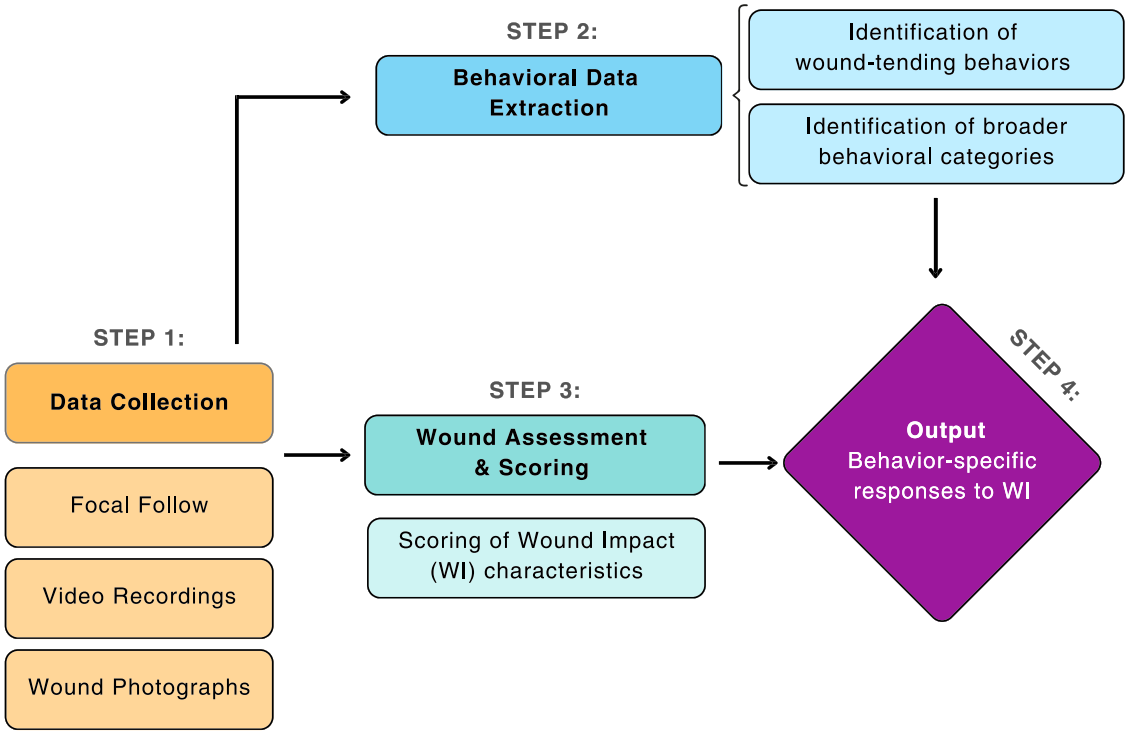

FIGURE 2 | Schematic overview of the analytical framework illustrating the integration of data extraction and wound assessment. The figure outlines the four sequential steps from data collection to wound assessment and inferential output.

approximately one newly detected wound every 30.4 observed days. When wound counts were standardized per age–sex class and their cumulative presence time (expressed as wounds per 100 presence-days), the highest wound rate was observed in the single adolescent male (15.7), followed by adult males (14.7; $N = 8$), subadult females (12.2; $N = 5$), juvenile females (7.73; $N = 2$), and adult females (4.89; $N = 13$). Overall, three body regions accounted for approximately 78% of all recorded wounds. The upper limbs were the most frequently affected, representing 30.36% of the total wounds ($N = 167$), followed by upper trunk (28.36%, $N = 156$), and lower limbs (19.09%, $N = 105$).

3.2 | Wound Characteristics: Structure and Variability

WI characteristics were calculated for 345 wounds observed on the first day of assessment, across 26 individuals within the study community. Across the dataset, we determined the distribution of each WI characteristic in relation to the number of observations (Figure 3). Severity scores were generally low (range: 1–5; median: 2), indicating that most wounds were mild to moderate at the time of assessment. Frequency counts showed severity score 2 in 133 wounds (~35%), score 1 in 122 wounds (32%), and score 3 in 97 wounds (~26%). Scores for edge characteristics (range: 0–4; median: 4) suggested that most wounds exhibited attached and advancing edges, consistent with active wound healing processes. On the first day of assessment, an edge score could be attributed to 163 wounds (~47%). Also, the status of wound surface followed a positively skewed distribution (range: 0–4; median: 4), reflecting that most wound surfaces were clean and rarely showed signs of advanced infection. Clean surfaces (score 1) were detected in 247 cases (~71.4%). Additionally, mobility scores (range: 1–4; median: 3) indicated that wounds were more frequently located on body parts subjected to moderate to high mechanical stress, such as limbs or joints. The distribution was slightly negatively skewed, with 127 cases reporting a mobility score of 3 (~36.7%).

3.3 | Wound-Tending Behaviors

Among the 27 predefined wound-tending behaviors, we identified 18 distinct wound-tending behaviors grouped into five behavioral categories: (1) inspect—*look, move hair, open, peer, smell, touch*; (2) clean—*apply saliva, dab leaves, lick, mouth, press, remove dead skin, remove dirt*; (3) prevent—*cover, repel insects*; (4) other—*maintain, scratch*; (5) topical application—*apply insects* (for illustrative examples of behaviors, see Figure 4 and the video clips in the repository: https://osf.io/3a6et/overview?view_only=9e916255632142f582eb093490945822). Captions for the videos can be found in the Supplementary Material).

3.4 | Case-Based Demonstration of the Framework

To illustrate how the proposed framework operates in practice, we present three representative case studies selected to capture the multilayer variation in visible wound characteristics and behavioral responses. For each case, wound characteristics (Table 3) are examined alongside the temporal structure and composition of wound-tending behaviors (Figures 5–7). All behaviors shown in the selected examples are self-directed. Results are presented for a subset of observation days for which photographic docu-

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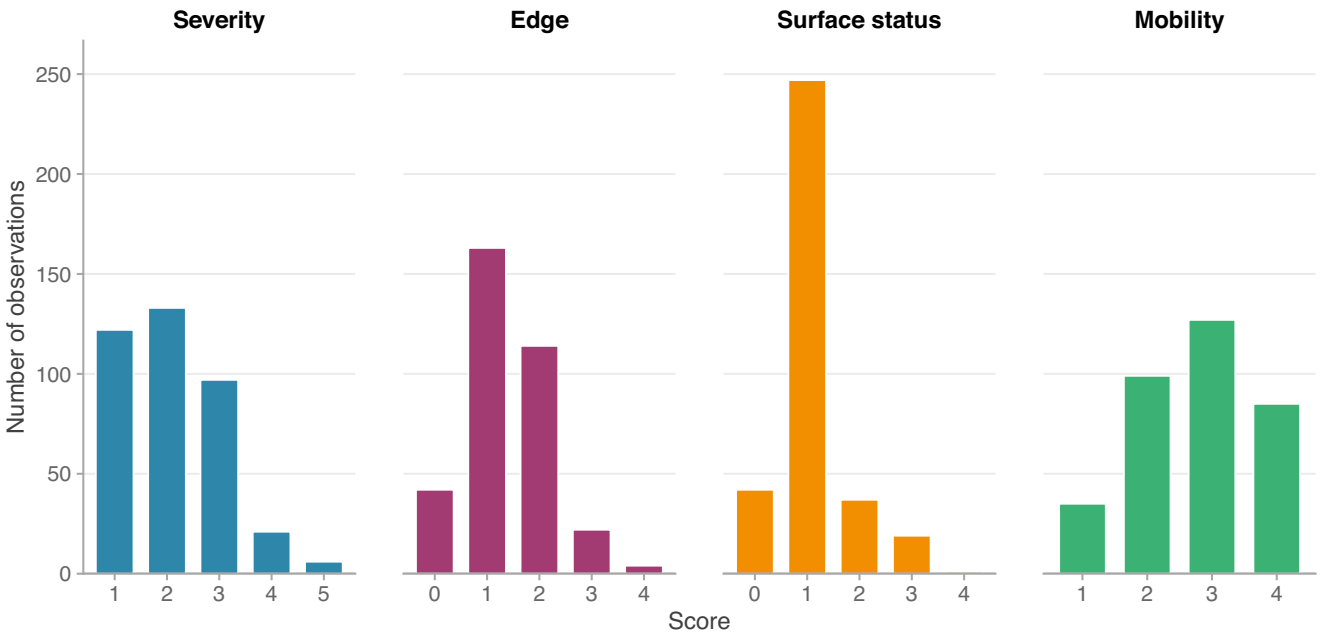

FIGURE 3 | Histogram of scoring values of four wound characteristics across 345 wounds. Severity (range: 1–5; median: 2); surface status (range: 0–4; median: 4); edge characteristics (range: 0–4; median: 4); mobility (range: 1–4; median: 3).

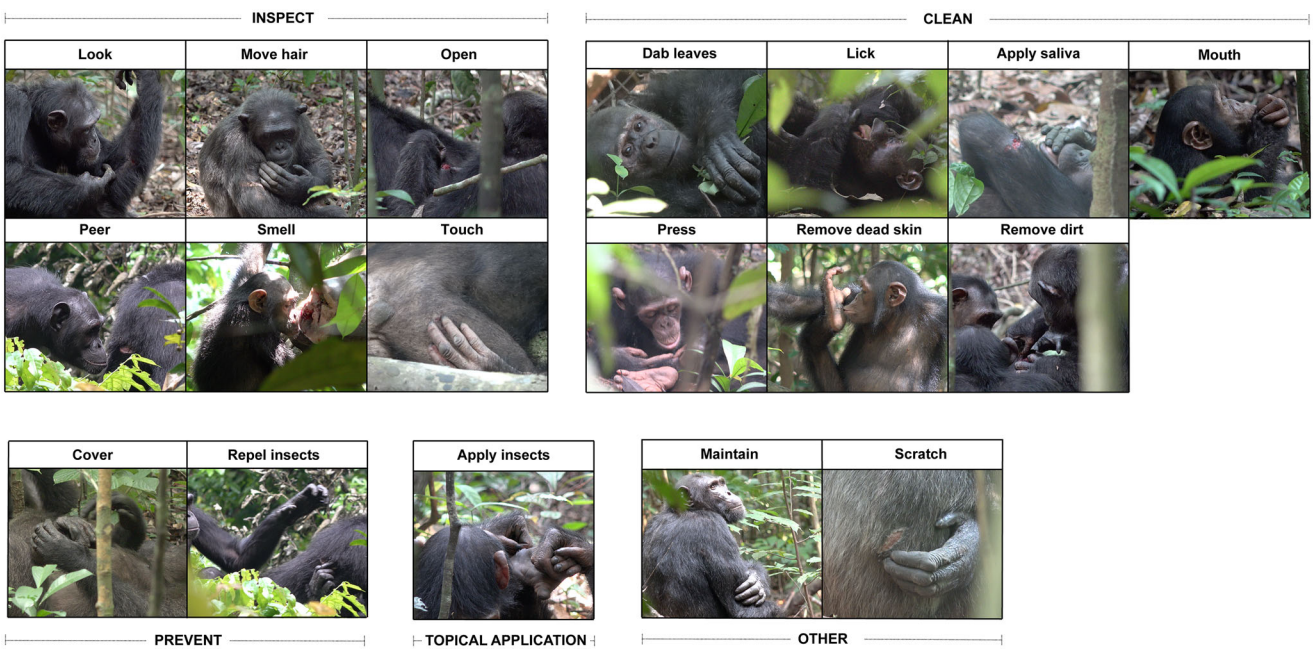

FIGURE 4 | Wound-tending behaviors and their functional categories in the Rekambo chimpanzee community. Representative video examples are available in the associated data repository.

mentation was supported by focal behavioral observations. Day numbering began at 0, on the day the wound was acquired, with subsequent days reflecting the wound's progression over time. These cases are not intended to reflect community-level behavioral frequencies; instead, they illustrate different situations and demonstrate how wound characteristics and behavioral responses can be jointly analyzed using the proposed framework.

3.4.1 | Case 1: High-Impact Wound (Severity 4)

This case exemplifies a high-impact wound (severity score = 4), characterized by deep tissue involvement and clear tissue exposure (Figure 5B and Table 3). The wound was positioned on the left lateral abdomen, a region subject to moderate mechanical stress. On day 1, the surface appeared clean (surface score = 1), with no visible signs of contamination, including dirt, pus,

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TABLE 3 | Study Cases 1–3: wound characteristics across observation days.

	Day	Severity	Mobility	Surface status	Edges
Study case 1	1	4	2	1	3
	4	4	2	3	3
	14	3	2	1	1
Study case 2	0	3	4	2	2
	2	3	4	2	1
	10	3	4	2	1
Study case 3	1	2	3	3	2
	2	NA	3	NA	NA
	4	2	3	1	1
	7	2	3	1	1

Note: Scores are reported for severity, mobility, surface status, and edges condition. See Figures 5–7A,B for corresponding wound images and wound-tending behaviors.

or discoloration. The wound edges were partly unattached and poorly defined (edges score = 3). By day 4, changes in wound characteristics were reflected by a degradation in surface status to score 3, due to the emergence of a localized infection indicated by intensified redness, particularly along the internal margin. Over subsequent days, as wound healing progressed, the edges gradually reattached to the wound bed, and epithelial borders advanced from opposing sides, reducing wound severity to score 3, and surface status and edges to 1 by day 14.

Wound-tending behaviors were frequently observed throughout the case (Figure 5A). Across 3 days, the individual was followed for 27:00 h (day 1 = 06:55 h; day 4 = 09:18 h; day 14 = 11:47 h). Time spent on wound tending was relatively low compared to other activities, varying across days: day 1 = 5.72% (00:32 h), day 4 = 3.0% (00:15 h), day 14 = 0.3% (00:01 h). On day 1 and day 4, when score values were highest, the subject exhibited the greatest behavioral investment, as measured by the number of observations and behavioral diversity. Observed wound-tending behaviors spanned all identified behavioral categories on the first day of observation. Cleaning actions predominated, with *apply saliva*, *dab leaves* being the most frequently observed. On day 4, when the surface showed signs of infection, the most common action remained *apply saliva*, followed by *smell* and *remove dirt*. As healing progressed, wound-tending behaviors became less frequent and shifted predominantly to a single event, *apply saliva* on day 14. The overall frequency and diversity of behavioral engagement visibly declined over time.

3.4.2 | Case 2: Moderate-Impact Wound (Severity 3)

The second case illustrates a wound with moderate tissue disruption and exposure (severity score = 3) located on the right foot, extending from the sole to the lateral side (Figure 6B and Table 3). This body part is subject to extreme mechanical stress (mobility score = 4) and frequent exposure to contaminants that significantly impact healing. Due to the wound's position and consequent persistent exposure to environmental contaminants, the surface status remained at score 2 across 10 observation days. However, unlike in Case 1, the epithelial border showed the earliest sign of advancement starting on day 2.

Behavioral patterns reflected this sustained WI (Figure 6A), with wound-tending behaviors remaining frequent and diverse across observation days. Across 3 observation days, the individual was followed for 17:40 h (day 0 = 03:18 h; day 2 = 04:24 h; day 10 = 09:56 h). Time spent on wound tending remained comparatively low relative to other activities, consistent with Case 1, varying across days: day 0 = 1.38% (00:09 h), day 2 = 7.7% (00:20 h), day 10 = 1.3% (00:08). As in Case 1, cleaning was the most represented category, while the most common individual behavior was *maintain*. Infrequent behaviors were also observed, including *apply insect* on day 0 and *remove dead skin* along the wound edge on day 10.

3.4.3 | Case 3: Low-Impact Wound (Severity 2)

The third case illustrates a shallow wound with minimal tissue disruption (severity score = 2) on the right thigh (Figure 7B and Table 3). Limbs are body regions with high mobility (movement score = 3) and are generally accessible to the injured individual for self-directed wound care. On day 2, severity, surface status, and edge characteristics scores could not be reliably assessed due to insufficient visibility, underscoring the framework's conservative approach to incomplete wound data. In such cases, reliable observable components, such as movement exposure, are still considered, and features that cannot be confidently evaluated are not scored. Across 4 observation days, the individual was followed for 37:35 h (day 1 = 09:42 h; day 2 = 10:07 h; day 4 = 07:30 h; day 7 = 10:16 h). Consistent with the lower WI, time spent on wound tending was lower than the previous two cases, varying across days: day 1 = 0.6% (00:03 h), day 2 = 0.2% (00:01 h), day 4 = 1.3% (00:05), day 7 = 0.2% (00:01).

Behavioral patterns associated with this case (Figure 7A) showed a progressive reduction in the diversity and frequency of wound-tending behaviors across observation days. On day 1, the behavioral repertoire was relatively broad and dominated by cleaning behaviors, particularly *apply saliva*, alongside with *remove dirt*

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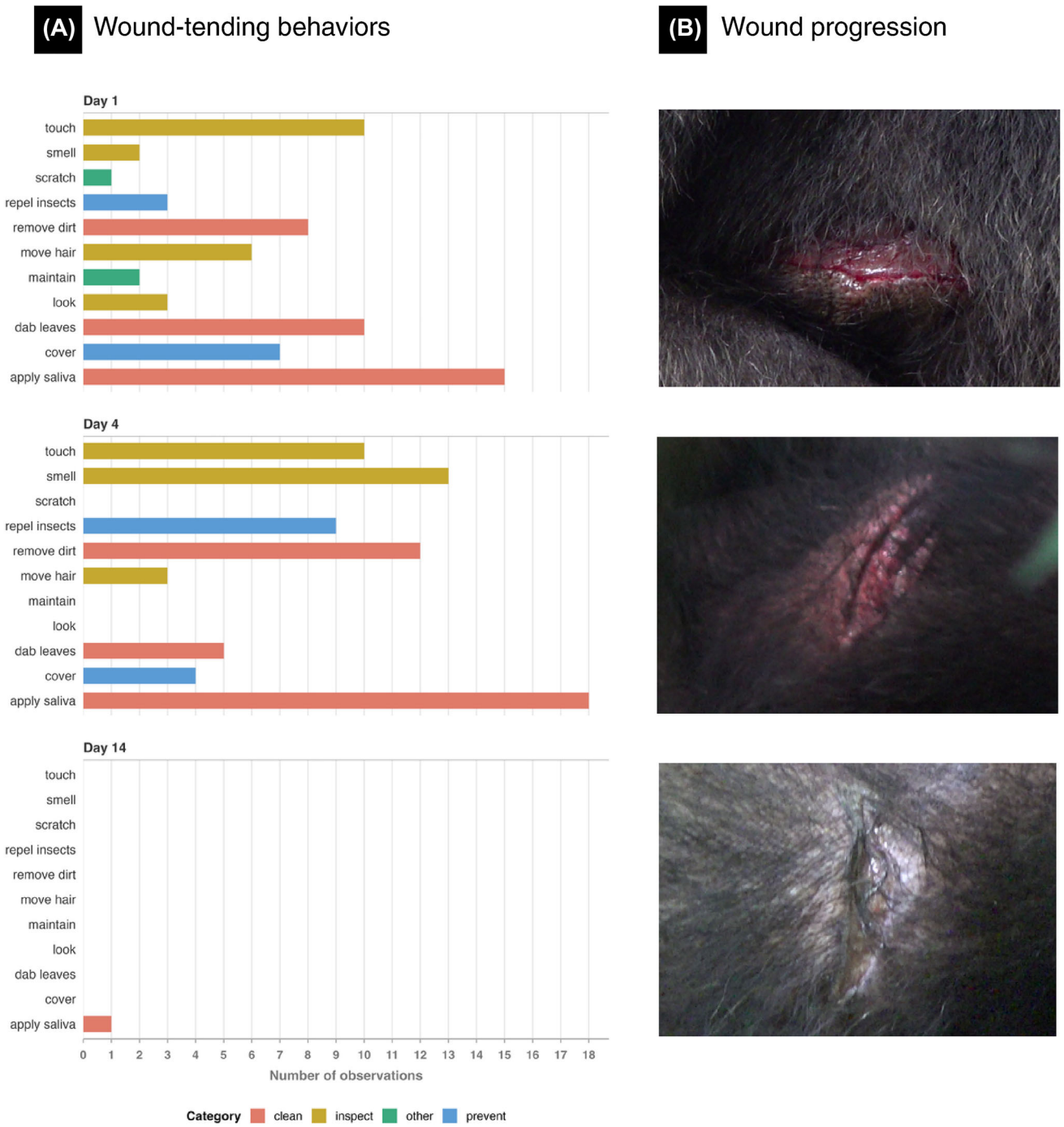

FIGURE 5 | Case 1: Wound located on the left side of the abdomen (adult male). (A) shows the temporal pattern of wound-tending behaviors, whereas (B) illustrates their distribution across healing stages in relation to wound impact (WI) scores.

and preventive behaviors such as *repel insects*. From day 2 onward, the behavioral profile becomes increasingly simplified, with cleaning behaviors such as *apply saliva*, *remove dirt*, and *dab leaves* remaining the most represented behavior on day 2, and inspection behaviors such as *look* and *move hair* being considerably represented on day 4. Notably, *application of insect* was recorded across 3 out of 4 observation days, including those characterized by low wound-tending behavioral activity, such as day 2.

4 | Discussion

In the present study, we had two goals. First, we aimed to fill gaps in existing approaches and methodological tools from human and nonhuman wound behavior research to enable systematic assessments of wound conditions across different mammal species. Second, we demonstrated its application to the study of wounds and wound-tending behaviors in a mammal species, chimpanzees. We illustrated the framework using a comprehensive dataset of 550 wounds from eight adult males,

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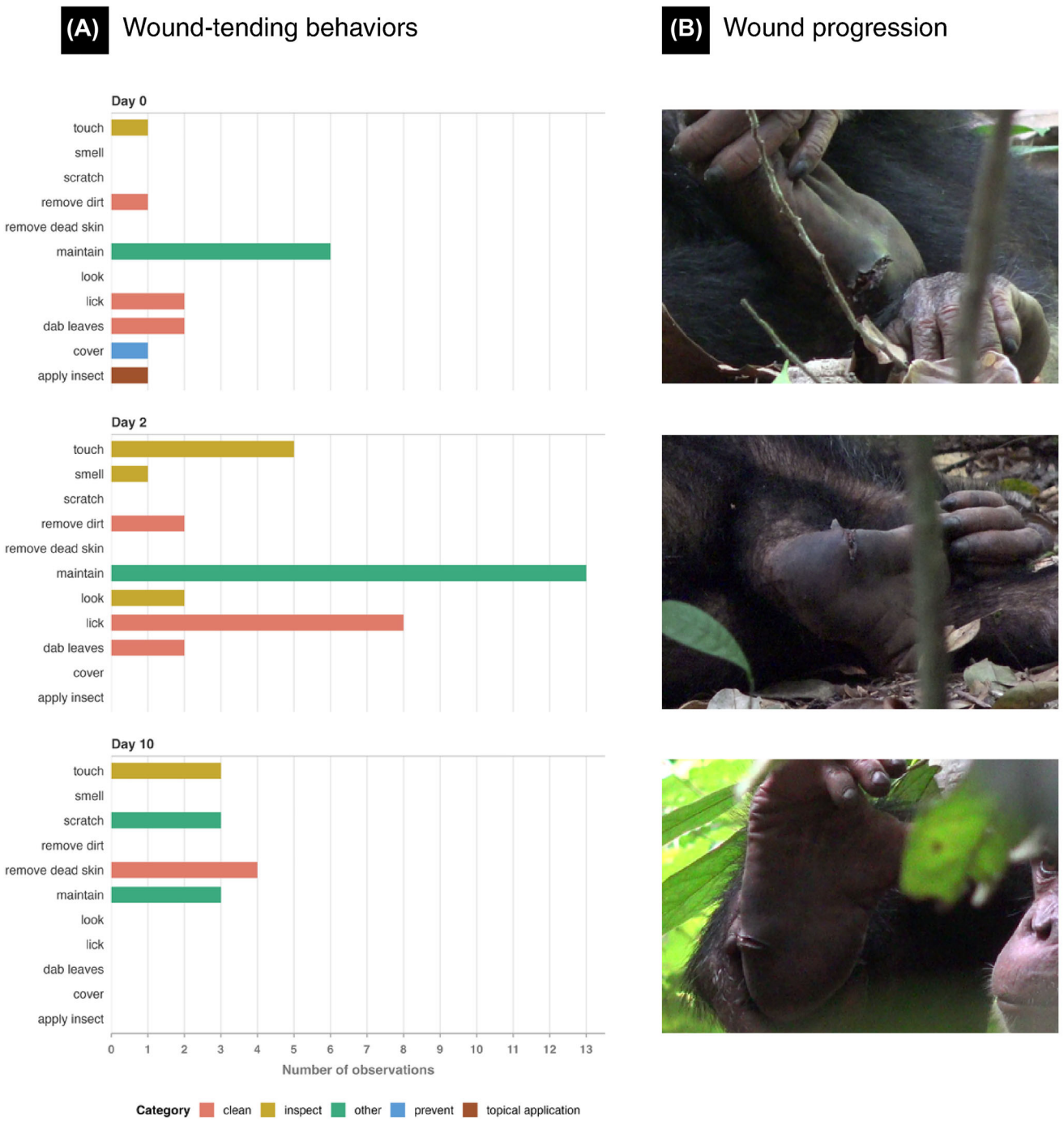

FIGURE 6 | Case 2: Wound located at the base of the right foot (juvenile female). (A) shows the temporal pattern of wound-tending behaviors, whereas (B) illustrates their distribution across healing stages in relation to wound impact (WI) scores.

nine adult females, and 13 immature individuals living in a community in their natural environment.

As demonstrated in the case examples (Figures 5–7), variation in WI profiles was consistently associated with distinct healing trajectories and behavioral responses. Declining scores were accompanied by a progressive reduction in behavioral investment and a simplification of repertoire, consistent with adaptive modulation of care effort. Conversely, injuries exposed to persistent mechanical and environmental stress, as observed in Case 2 where the wound was located on the lateral sole of the foot, elicited a diverse repertoire of wound-tending behavior. In this context, the behavior *maintain* appears to play a stabilizing role, mitigating environmental contamination and mechanical disturbance. Importantly, the persistence of infrequent behaviors such as *application of insect*, even under low-impact conditions (see Case 3), indicates that certain wound-tending responses may not exclusively be driven by mechanical constraints but could reflect additional regulatory or preventing functions, or also individual preferences.

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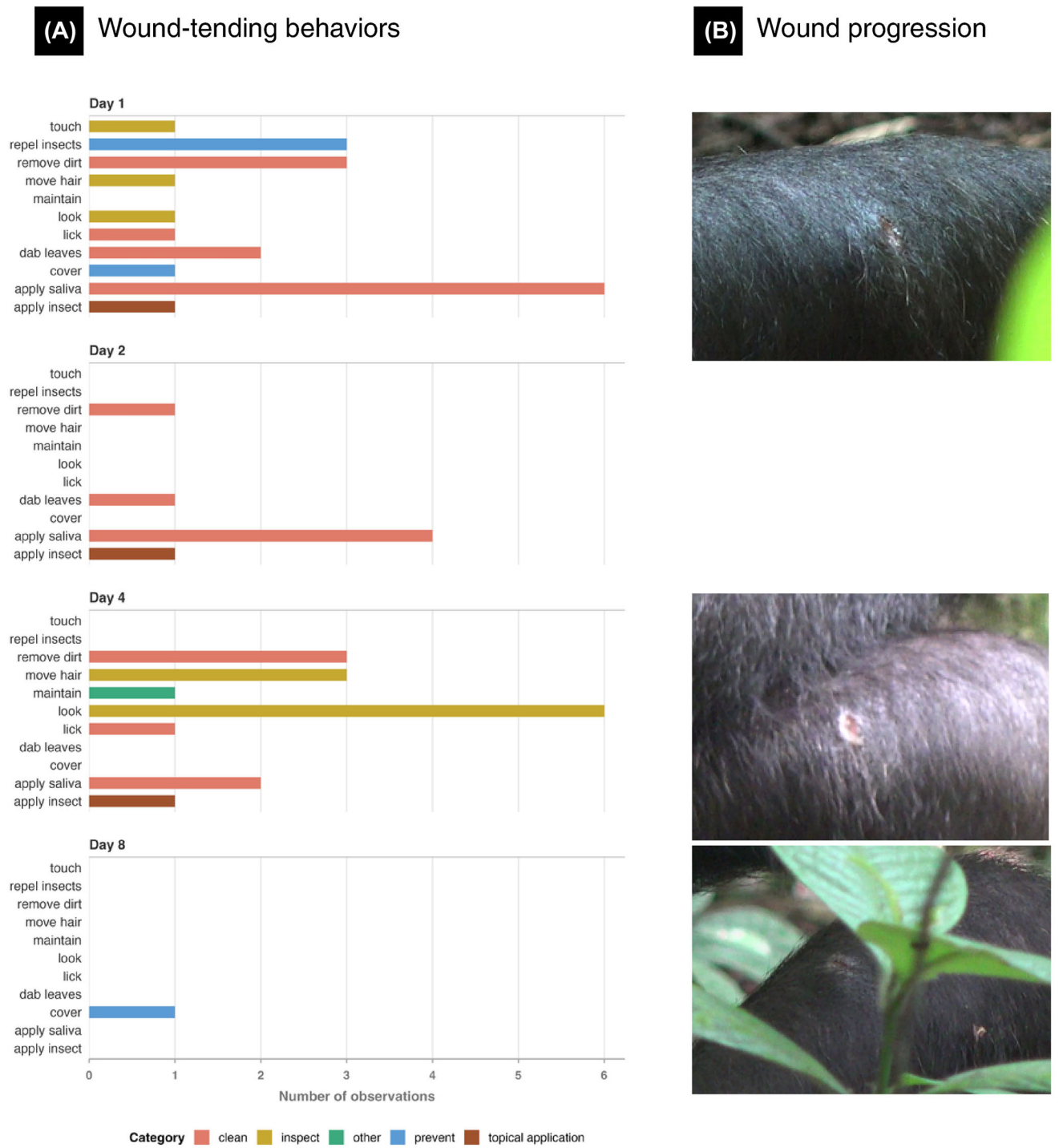

FIGURE 7 | Case 3: Wound located on the right thigh (subadult female). (A) shows the temporal pattern of wound-tending behaviors, whereas (B) illustrates their distribution across healing stages in relation to wound impact (WI) scores.

The distribution of the four wound characteristics (severity, surface status, edge, and mobility) (Figure 3) indicated that only a small portion of the injuries reached high-impact levels, while moderate-impact wounds predominated. This pattern aligns with previous findings in chimpanzees [61, 78], and suggests that although aggression is frequent, most injuries do not result in severe functional impairment. This conclusion aligns with considerations about both the group's resilience and individual fitness. Although intragroup tensions over reproduction and food competition frequently lead to aggression, maintaining a functional, healthy community remains essential for individual survival, particularly in the presence of neighboring, competing communities. While injuring group members may offer short-term advantages, such as improved access to food or mates, inflicting severe wounds can result in permanent physical impairments or even death, thereby impacting individual fitness [107–109]. At the same time, the high rates of aggression in chimpanzee subspecies, combined with their advanced cognitive

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abilities, may help explain the exceptionally diverse repertoire of wound-tending behaviors observed in this study.

The expanded ethogram (Table 1)—integrating behaviors documented across nonhuman animals with newly identified behaviors from our study community—was developed to support a more comprehensive basis for comparative studies across animal taxa. To accommodate the wide variation in observational contexts—from high-resolution datasets that permit fine-grained behavioral distinctions to contexts where only broad patterns can be reliably detected—we implemented a two-level analytical structure distinguishing between specific behaviors and broader functional categories. This design is particularly relevant for species that cannot be reliably observed at close range or for extended periods of time, such as study groups that are poorly accustomed to human presence or arboreal species, as well as for datasets derived predominantly from ad libitum observations. In such contexts, the occurrence of broad behavioral categories can still provide meaningful insights on the impact of a wound and the investment an individual makes in managing it. As a result, the approach remains robust and informative across a range of behavioral settings, facilitating reliable comparisons even when data granularity is limited. The behavior *dab leaves* was included in the *cleaning* category following its widely accepted blood-wiping function and the method of leaves handling (unprocessed leaves, usually folded in mouth or licked between applications) [4, 63, 65, 68, 96, 110] and kept separated from the application of organic and nonorganic material with medicinal or potential medicinal properties included in the category *topical application* [29, 44–46]. Over the 31 months observation period (7-month pilot phase plus 24 months of systematic data collection), our analyses identified 18 distinct wound-tending behaviors out of an ethogram of 27—representing a degree of behavioral diversity far exceeding what has been reported in chimpanzees or any other nonhuman animal species [47, 52, 59, 61, 63, 67, 70, 98, 111]. Of the seven behaviors listed in the *topical application* category, only *application of insect* [56, 57] was documented in the study community. In contrast with what was previously documented in orangutans, we never observed the *application of chewed material* [55], namely, the visible act of mastication of material with the teeth, followed by its application to the wound surface.

Although the framework is presented here in its complete form, it has been intentionally designed to be adaptable to diverse contexts. Not all studies will allow for the same degree of behavioral resolution, photographic documentation, or wound tracking. Additionally, although we focused here on the relationship between wound-tending behaviors and WI's four main characteristics, the same procedure (behavior: scores) can still be applied to other behavioral domains if the aim is to assess the health state of the individual (e.g., the relation between wound features and feeding behavior). At a minimum, the framework requires: (i) consistent identification of behavioral events and (ii) basic assessment of WI (e.g., movement, severity). Under these conditions, a simplified version of the framework can be applied, and wound-tending behaviors (or any other behaviors) can still be analyzed as occurrence rates relative to wound state. With increasing data resolution, additional components can be incorporated, such as scoring values across days and the inclusion of all wound characteristics. Importantly, the framework's inferential logic remains unchanged across levels of detail, allowing wound-tending to be examined as a context-dependent behavioral response even when data are limited.

While WI integrates multiple observable features of wound condition, its resolution is ultimately shaped by the constraints of noninvasive assessment—whether observations are made at a distance in the field or in any setting where direct clinical examination is not possible. Despite these limitations, the framework provides a robust foundation for addressing key questions about the causal factors shaping healing durations and the behavioral strategies individuals employ to manage wounds. By establishing a structured system that links wound characteristics to behavioral responses, it enables investigations into how and why wound-tending decisions vary across individuals, contexts, and species.

Despite WI providing a robust framework for evaluating wound condition, certain physiological aspects—such as the exact proportion of granulation or necrotic tissue, or microbial load—cannot be assessed reliably without close-range observations and may, therefore, contribute to unexplained variation in WI and healing rates. One promising approach to address this gap lies in combining this approach with noninvasive longitudinal methods of health assessment, such as the collection of urine samples, which could allow monitoring of immune-related parameters and other physiological individual stress indicators [112–114]. Given that elevated stress is well documented to delay wound healing in humans [18, 115, 116], integrating such measures into future applications of the framework may offer a promising path toward a more comprehensive understanding of the mechanisms influencing wound recovery.

4.1 | Broader Applications and Future Directions

The WI framework, though developed for studying chimpanzees in the wild, includes aspects that are relevant beyond the model system and may stimulate both comparative and applied research. Because the WI relies exclusively on observable characteristics that can be assessed noninvasively from a distance, it provides a structured system for evaluating wound condition under constraints like those encountered in telemedicine (i.e., exchange of healthcare information across distances) [117, 118], home-care contexts, or low-resource settings [119, 120]. The framework's emphasis on functional WI—integrating severity, mobility, surface condition, and edge characteristics—aligns closely with clinical recognition that visual severity alone does not predict healing trajectories [102, 121]. Moreover, linking wound state to behavioral responses provides a theoretical framework for understanding how human patients spontaneously protect, clean, or monitor wounds in daily life, and how such behaviors may reflect the impact of wounds or influence wound healing. Beyond these potential applications, the framework also provides a foundation for future comparative research across species. For example, it enables investigations into whether aggressors strategically modify attacks based on target characteristics—such as sex, age classes, dominance status—and whether such strategies result in systematic differences in WI or whether tissue properties play a dominant role in healing trajectories and the behaviors performed. Furthermore, the framework provides a standardized basis for future quantitative analyses aimed at testing associations

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between wound characteristics, wound-tending behaviors, and healing trajectories across individuals and contexts. Additionally, incorporating anatomical and biomechanical information may shed new light on how tissue properties and the mechanical environment of different body regions shape both healing trajectories and wound-tending responses. Integrating these dimensions into future applications of the WI could deepen our understanding of the interaction between morphology, injury, behavior, and healing, while contributing to broader perspectives on the evolutionary roots of medical care.

5 | Conclusion

The repertoire of behavioral responses toward injuries in nonhuman species has so far been limited to sparse, often anecdotal reports, largely due to constraints imposed by distance-based observations and the absence of a structured ethogram. As a result, a unified cross-species framework for systematic comparisons of wound-tending behaviors was lacking, and the dynamic relationship between wound condition and behavioral responses remained largely unexplored. The WI framework introduced here addressed these gaps by providing a structured system for investigating wound-tending behaviors as dynamic responses to WI. Because wounds influence both individual survival and reproductive success, the strategies individuals adopt to mitigate their effects may offer valuable insights into the diversity of behavioral solutions across species and the potential role of advanced cognitive abilities in shaping them. Nonhuman animal species often display remarkable evidence of wound healing, yet the behavioral diversity underlying these responses, and their frequency vary with wound characteristics, has yet to be studied. The nature and degree of medical knowledge in the context of wound-tending among nonhuman species is still an open field, and it is likely that the number of behaviors documented here will continue to expand as new observations accumulate. In the future, we might be able to empirically compare wound-tending strategies and healing dynamics across taxa. Doing so will deepen our understanding of the evolutionary roots of medicinal behaviors and medical cognition and may also offer insights relevant for improving animal care in captive settings and inspiring new approaches for human wound management.

Author Contributions

A.M.: Conceptualization, development of protocol, data collection, data curation, formal analysis, funding acquisition, investigation, Writing – original draft, Writing – review and editing. M.G.: Conceptualization, formal analysis, supervision, Writing – shaping of manuscript, review and editing. F.M.: Data collection, data curation, Writing – review and editing. G.W.E.E.: Writing – review and editing. T.D. and S.P.: Conceptualization, methodology, supervision, funding acquisition, project administration, Writing – shaping of manuscript, review and editing. All authors read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting this study can be requested from the corresponding or the last author. Descriptive video footage of wound-tending behaviors is available at the following repository: https://osf.io/3a6et/overview?view_only=9e916255632142f582eb093490945822.

Peer Review

For transparency, the peer review documents associated with this article are available at https://doi.org/10.1111/nyas.70414.

Ethic Statement

The present study was entirely observational and noninvasive. According to the German Animal Welfare Act of 25th May 1998, Section V, Article 7, our study was classified as a nonanimal experiment and did not require approval from any relevant body. The study adhered to the relevant national and institutional guidelines for animal care and use. Observers followed a strict hygiene protocol, including a 5-day quarantine and the wearing of face masks when near chimpanzees. Our research adhered to the legal requirements of Gabon and followed the recommendations of the "Animals (Scientific Procedures) Act 1986" by the UK government and the principles of "Ethical Treatment of Non-Human Primates" by the American Society of Primatologists. The Agence Nationale des Parcs Nationaux and the Center National de la Recherche Scientifique et Technique of Gabon (CENAREST), Libreville, Gabon, granted the relevant permits for research in the Loango National Park.

OCP Consortium

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