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REVIEW ARTICLE

Rediscovering Sushruta's Bandaging Techniques: A Modern Analysis of Material Innovations and Non-invasive Healing Strategies for Chronic Wounds

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Abstract

Background: The ancient *Ayurvedic* text Sushruta Samhita has elaborate descriptions of wound care, including very advanced bandaging methods that are still relevant to modern medical practice. With a focus on infection prevention, pressure retention, and comfort for the patient, Sushruta described 14 bandaging methods, each tailored to regions and types of wounds. His insight into wound dynamics and healing was groundbreaking, using materials such as cotton, silk, and herbal infusions. **Aim:** The current study re-evaluates Sushruta's bandaging methods and explores their potential applications in wound care, particularly treating chronic wounds, resource constraints, and antimicrobial resistance. **Methods:** By reviewing Sushruta's principles and recent developments, such as antimicrobial nanofiber dressings, hydrogel-based wound care, and biodegradable polymers, this review explores how these ancient practices can be combined with current medical technologies to provide cost-effective, environmentally sustainable solutions. **Results:** Sushruta's *Kosha Bandha* for fracture is similar to modern splint bandages, and *Mandal Bandha* for cylindrical body areas is identical to compression treatment for venous ulcers. Sushruta's approach is highly adaptable, with the current focus on personalised and patient-centric care. Furthermore, materials such as drug-eluting dressings and *Ayurveda*-based smart bandages are opening avenues for targeted therapy and real-time monitoring of healing wounds. **Conclusion:** Combining Sushruta's principles with current materials science can bridge healthcare gaps, especially in resource-poor environments. This integration can improve patient outcomes, providing sustainable and cost-effective solutions to wound care.
Major Findings: Since ancient times, Sushruta's principles of wound care are very relevant today, providing practical, cost-effective solutions when combined with contemporary innovations such as smart bandages and biodegradable polymers.

Keywords: Antimicrobial Wound Therapy, *Ayurvedic* Wound Care, Bioengineered Materials, Chronic Wound Management, Nanofiber Wound Dressings, Sustainable Bandaging

1. Introduction

The art of surgery and wound care, noted in the Sushruta Samhita, one of the oldest treatises on medicine, is a testament to advanced knowledge by the physicians of ancient India. This medical compendium, written by Acharya Sushruta around 1000 BCE, established an approach to healthcare as holistic and systematic in accounting for surgery, anatomy, pathology, and therapeutic care. It contained not only surgical instruments but an elaborate description of the procedure, including plastic surgery and various suturing techniques, along with *Bandhana Karma*, which is bandaging techniques necessary for handling trauma and wound healing[1,2].

Management of chronic wounds in modern medicine remains a massive problem because of

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factors that include bacterial infections, inappropriate dressing of wounds, and resource inadequacy. Sushruta's techniques for bandaging, found to be both anatomically precise and conducive to the material used, reflect contemporary healthcare considerations that are more specific, economical, and ecologically friendly. Rediscovery of these techniques can give a clue towards accomplishing an affordable, biocompatible solution for chronic wound management, which can either supplement or partly replace expensive, exotic materials[3].

Sushruta's 14 *Bandhana Karma* techniques were specific to particular anatomical and pathological contexts, translating to the emphasis on injury-specific bandaging methods today. For example, detailed bandaging recommendations for facial injuries, splints around the fingers, and complicated joint dressings reflect a deep understanding of the wound dynamics, infection, and the need for securing dressings based on location and type[4,5].

The field of wound care has transformed from what Sushruta knew with improvements in materials, the latest hydrogel dressings, and nanofiber gauzes to silicone-based products that afford properties, including antimicrobial action, retention of moisture, and adaptation. Still, using natural materials, like cotton and medicinal herbs, shows Sushruta's early commitment to biocompatibility and eco-friendly practices that emphasise today's mantra of sustainability and smaller environmental footprints in health[6].

Sushruta has thrown light on many concepts today, like natural antiseptics for infection control, the right amount of pressure application for vascular wounds, and particular techniques to limit scarring. The approach also included managing step-by-step wound care with applications and removals and readapting dressings at scheduled intervals, much like postoperative care these days[7,8].

It throws the psychological and physiological aspects of wound care into the light and asserts that comfort and stabilisation form essential segments of the healing process. This can assist in better managing wounds in patients, especially in rural or low-resource settings, where access to such high-tech materials is not easy, by integrating the principles of Sushruta's bandaging with contemporary materials and innovations. This method may reduce the reliance on antibiotics and chemical dressings, which directly will play into global needs regarding reductions in antimicrobial resistance and resource scarcity[9,10].

Sushruta's innovations in wound care, particularly his bandaging techniques, have a lasting legacy in modern surgical processes. Bhattacharya11[1] mentioned the historical importance of Sushruta's procedures, particularly his emphasis on infection control and pressure adjustment, the pillars of current wound care. Dev *et al.*,[12] discussed the surgical procedures in the Sushruta Samhita, emphasising their adaptability to contemporary patient-centred practices. Kumar[13] discussed how Sushruta's bandaging techniques are adaptable to contemporary materials such as hydrogel dressings and nanofibers, ensuring their ongoing relevance in contemporary wound care. Bagde *et al.*,[14] further discussed how Sushruta's bandaging techniques compare to contemporary methods of treating chronic wounds and fractures. Mishra[15] emphasised the progression of surgical wisdom, demonstrating how Sushruta's procedures are still applicable, particularly in a resource-poor environment, as exemplified in Table 1[11-15].

2. Materials and Methods

2.1 Locating Data

Literature regarding Sushruta's wound care practice was accessed from scholarly journals, ancient texts, and modern research databases.

2.2 Data Collection

Relevant articles, books, and studies on Sushruta's practice and applications in the present times were considered.

2.3 Data Extraction

The main findings, issues, and possible applications were taken from each source to compare ancient practices and contemporary approaches.

2.4 Synthesising Data

The findings were classified and grouped based on relevance to contemporary wound care and interest in modifying Sushruta's techniques to contemporary practice.

Table 1. Key contributions and modern correlations of Sushruta's bandaging techniques[11-15]

Authors (Year)	Key Finding	Research Focus	Challenges/ Limitations	Future Scope
Bhattacharya S (2012)[11]	Infection control and pressure modulation are essential in wound healing.	Relevance of Sushruta's wound care methods	Lack of detailed comparisons with modern methods	Further integration with modern dressings and techniques.
SDev S. *et al.* (2015)[12]	Sushruta's surgical techniques align with modern patient-centred care practices.	Ancient surgical practices in wound care	Limited focus on practical applications today	Implementing in resource-limited settings.
Kumar A (2021)[13]	Sushruta's bandaging methods correlate with modern nanofiber and hydrogel dressings.	Bandaging techniques in wound management	Need for experimental validation in clinical settings	Exploring biodegradable polymers in wound care.
Bagde *et al.* (2018)[14]	Sushruta's concepts are similar to modern methods used for fractures and ulcers.	Comparison of ancient and modern methods	Generalisability to diverse wound types is limited	Broader application in chronic wound care.
Mishra B (2020)[15]	Sushruta's techniques remain relevant in modern wound care, especially in underserved areas.	Evolution of surgical knowledge	Lack of contemporary comparative data	Combining Sushruta's methods with modern tech in developing countries.

Legend: These studies, collectively, paint the pragmatic usability of ancient wisdom in surgery and its relevance to modern days, especially regarding treating wounds and infections and sustainable medicine. This congruence between the methods of Sushruta and modern non-invasive treatment makes it possible for integrative healthcare solutions to be drawn from diverse medical contexts.

3. Result

3.1 Historical Context of Bandaging Techniques in Sushruta Samhita

Sushruta is considered the "Father of Surgery," his text, Sushruta Samhita, has evolved as the first cohesive approach to medical science. The ancient compendium exposed well-rounded practices in surgery, including bandaging, known as *Bandhana Karma*, which proved essential to trauma care and had an important role in surgical recovery and the management of chronic wounds. Bandaging was part of *Shalya Tantra* or surgery in *Ayurveda* because it improved wound healing and prevented complications[16].

3.2 Evolution of Bandaging Practices

Sushruta's work uses bandaging to stabilise wounds, control bleeding, and prevent infection. His accumulation of 14 *Bandhana Karma* techniques emphasises a deep understanding of anatomy and an appreciation of the relations between material properties and biological healing. Bandages were used in ancient times to immobilise injuries, cover the wound site, and absorb medicinal applications.

The innovations made in Sushruta's techniques were not just limited to physical stabilisation; they also targeted patients' psychological comfort, minimising aspects of pain and maximising movement ease. This puts the beginning blocks of modern principles of care-ergonomic and patient-centred[17,18].

3.3 Global Relevance

All wound care today integrates Sushruta's practices. The principles of compression for venous ulcers and similar ideas of compression therapy used by modern principles are based on the Optimal *Bandha* by Sushruta are followed. His aversion to having knots at the wound site and the practice of specific tightness of bandage as appropriate for different body regions are also observed in modern surgical practice, as depicted in Table 2[19,20].

3.4 Detailed Explanation of Sushruta's 14 *Bandhana Karma* Methods

The 14 *Bandhana Karma* [bandaging techniques] discussed in Sushruta Samhita constitute some of the specialised qualities of ancient Indian medicine. They were created considering the knowledge of human

Table 2. Key historical insights and their modern relevance[19,20]

Historical Insight	Modern Correlation	Application in Healthcare
Avoid knots over wounds.	Pressure-free dressing techniques	Reduces wound pain and prevents ischemia
Different bandage tightness	Compression therapy	Venous ulcers and lymphatic drainage
Use of cotton and silk	Biocompatible materials like gauze	Infection prevention and wound healing

Legend: Summary of historical insights from Sushruta's bandaging techniques and their modern healthcare applications.

anatomy, biomechanics, and the healing processes within the body. Every technique was followed with a particular injury, anatomical region, or pathological condition to achieve stability, protection, and healing[21].

3.5 Anatomical and Functional Accuracy

Sushruta classified the different bandages based on the shapes they were made, the region where they were applied, and the type of lesion they covered. Therefore, each bandage type played a physical role, reducing pain while assisting in physiological recovery. For example, when a fracture occurred, the *Kosha Bandha* splinted the fingers and thumbs, while *Swastika Bandha* [figure-eight bandage] stabilised the joints like the knees and elbows[22].

Sushruta avoided tightness that might lead to ischemia or discomfort, a principle that is applied today and is essential in compression treatments and dressings. The techniques ensured anatomical preservation with minimal restriction of movements and risk of further injury.

3.6 Modern Correlations

However, today's medical practices reflect many of the principles described in Sushruta's work. Techniques such as the figure-eight wrap for sprains, the spiral bandage for cylindrical body parts, and the circular bandage for securing primary dressings mirror the traditional *Bandhana Karma* methods shown in Table 3[23,24].

Table 3. Sushruta's 14 *Bandhana Karma* and their modern correlations[23,24]

Bandhana Karma [Ayurvedic Name]	Modern equivalent	Application/use case
Kosha Bandha	Finger splint	Fractures and dislocations of fingers and thumbs
Daam Bandha	Spica bandage	Narrow body parts like the genitalia
Swastika Bandha	Figure-eight bandage	Joints such as knees, elbows, wrists
Anuvellita Bandha	Spiral bandage	Cylindrical body parts like arms and legs
Pratoli Bandha	Circular bandage	Neck and cylindrical structures
Mandal Bandha	Spiral and reverse spiral bandage	Cylindrical areas like arms and thighs
Sthagika Bandha	Recurrent stump bandage	Distal parts like fingers and toes
Yamaka Bandha	Immobilisation bandage [Buddy tape]	Adjacent injuries or fractures requiring immobilisation
Khatwa Bandha	Four-tailed bandage	Jaw, cheeks, and facial structures
China Bandha	Eye patch	Injuries around the eyes
Bibandha Karma	Abdominal bandage	Abdominal wounds and postsurgical care
Vitana Bandha	Capeline bandage	Head injuries
Gophana Bandha	Chin or Barrel bandage	Chin, nose, lips, and shoulders
Panchangi Bandha	Sling	Upper limbs requiring suspension

Legend: Overview of Sushruta's 14 bandaging techniques and their modern healthcare equivalents and applications.

3.7 Materials Used in Ancient Bandaging and their Modern Equivalents

It makes it highly critical for material selection for bandaging, as mentioned in *Bandhana Karma*, which always leads to the wound healing process more comfortably and with minimal chances of complications. These materials, Sushruta, are categorised into layers based on texture, flexibility, absorbency, and compatibility with the human body. Such earliest materials include cotton, bark, silk, and

leather, thereby showing how deep an understanding must have been towards biocompatibility and dynamics of a wound even then, and hence still very relevant in contemporary medicine[25].

3.8 Traditional Wound Dressing Materials

Cotten Karpasa: It is one of the softest, absorbent, and breathable materials that can be used for wound dressing and absorbing exudate. It would mean comfort and significantly reduce irritation.

Bark: Stiff and durable, bark was used for splinting and bandages that needed stiffness, as in modern applications such as plaster casts.

Silk: With a smooth texture, it was utilised for sensitive areas to minimise friction over the injury.

Leather and Wool were used for strength and elasticity to ensure that compressions and immobilisations could occur in significant bandages[26].

3.9 Contemporary Analogues

Synthetic counterparts, including hydrogels, nanofibers, and silicone-based dressings, have been found. Their properties have considerably improved compared to the original ones, employing better moisture control, antimicrobial activity, and designed elasticity features[27].

3.10 Use of Ancient and Modern Materials

Hydrogels: This mimics the moisture-retaining ability of cotton for chronic wound care.

Nanofibers mimic silk-like breathability and adaptability but with superior antimicrobial ability.

Bandages: The bandage is a biodegradable polymer used as an eco-friendly alternative for bark. For more flexibility and strength, as shown in Table 4[28,29].

3.11 Significance of Material Selection

Along with discovering the ideal mixture of comfort, healing efficiency, and practicality, Sushruta's work on material selection found itself ascertaining the perfect combination of comfort and healing efficiency. His knowledge of properties that would include texture, elasticity, and medicinal properties even surmised the criterion used today for choosing wound dressing materials[30].

These principles have been adopted to a modern level of adaptation in designing wound care solutions with minimum environmental impact and maximum healing outcomes. Researchers and clinicians are, therefore, expected to innovate based on discoveries made from Sushruta's methodologies for designing new materials to be applied to various medical uses[31].

Table 4. Traditional and modern materials in bandaging[28,29]

Ancient material [*Ayurvedic* name]	Modern counterpart	Key properties
Cotton [*Karpasa*]	Sterile gauze, hydrogel dressings	Soft, absorbent, breathable
Bark	Biodegradable polymers	Structural support, eco-friendly
Silk	Nanofiber dressings	Smooth, reduces friction
Leather	Elastic bandages, compression wraps	Flexible, durable
Wool	Foam dressings	Insulation, absorbency
Metal Strips	Rigid supports, splints	Stabilisation
Medicinal Herbs	Antimicrobial dressings	Infection control
Fibres from Plants *[Luffa]*	Biodegradable meshes	Eco-friendly, absorbent
Alabu [Bottle gourd fibres]	Foam pads, cushioned dressings	Protection, cushioning
Plant bark adhesives	Adhesive dressings	Secures wound dressing

Legend: Comparison of traditional *Ayurvedic* materials and their modern counterparts with key properties in wound care.

3.12 Bandaging in Trauma and Non-trauma Wound Management

While bandaging techniques, *Bandhana Karma* of Sushruta Samhita, aim for the coverage of wounds. It not only describes the treatment of trauma wounds but also chronic wounds. Sushruta's approaches are based on anatomical precision, functional stability, and holistic care of injuries and conditions[32].

3.13 Bandaging in Trauma Wound Management

Appropriate *Kosha Bandha* [*splint bandage*] and *Swastika Bandha* [*figure-eight bandage*] were applied

to traumatic wounds, such as fractures, dislocations, and cuts. This resulted in immobilising injured parts, preventing undue pain, potential complications due to misalignment, and secondary infections.

3.14 For Major Trauma

Kosha Bandha: It was employed for fingers and other minor joint fractures, whose splinting techniques are still similar to modern usage[33]. *Mandal Bandha* was used for cylindrical parts like arms and legs, similar to a cast in modern times[34].

Sushruta's texts also carried the principles of not causing the bandages to constrict the blood circulation, but making them perfectly tight. This is related to the modern concept of compression bandaging, often carried out in acute injury management, like sprains and strains.

Bandaging in Non-Trauma Wound Management[35]. As he treated chronic sores, Sushruta claims that the bandages given to the patient were explicitly meant not to infect the condition, let alone promote healing and provide the patient with the utmost comfort. *Bibandha Karma*, or the abdominal bandage, was used in non-trauma conditions like hernia to keep the abdomen shaped and to help the same while recovering from surgery[36].

3.15 In the Non-trauma Scenario, Critical Applications Included

Diabetic wounds were treated with loose and absorbent bandages to preserve fragile skin from friction. Venous ulcers require tight binding to stimulate blood flow and reduce swelling.

3.15.1 Innovations Founded on Tradition

Modern practices, such as compression wraps for venous ulcers or adhesive dressings for surgical wounds, find their origins in the principles of Sushruta. His emphasis on anatomical fit and avoiding pressure over sensitive areas aligns very closely with today's wound management protocols, as shown in Table 5[37,38].

3.16 Innovations in Bandaging: From Sushruta to Modern Biocompatible Materials

The transition from ancient bandages to modern biocompatible materials reflects the ongoing relevance of the Sushruta postulates. Ancient materials like *Karpasa* and bark proved very effective during their time. However, medical science has advanced, leading to innovations in materials that can produce functionality and enhance healing properties[39].

4. Evolution from Traditional to Modern

Sushruta's *Daam Bandha* [*spica bandage*], used for narrow parts like the genitalia, has its modern version in elastic polymer compression garments. *Mandal Bandha [spiral bandage]* has been made into stretchable synthetic wraps for cylindrical body parts.

Material science innovations have also led to the following:

(i) *Hydrogels:* These retain moisture at the wound site, like cotton, but are cool.

Table 5. Role of bandaging in trauma and non-trauma wounds[37,38]

Application type	*Bandhana Karma* [*Ayurvedic* term]	Modern equivalent	Benefits
Fractures	*Kosha Bandha*	Splint bandage	Stabilises broken bones
Joint injuries	*Swastika Bandha*	Figure-eight bandage	Provides mobility while securing the joint
Chronic ulcers	*Gophana Bandha*	Barrel bandage	Protects and cushions the wound
Venous ulcers	*Mandal Bandha*	Compression bandage	Improves circulation, reduces swelling
Abdominal wounds	*Bibandha Karma*	Abdominal wrap	Postsurgical care and support
Eye injuries	*China Bandha*	Eye patch	Shields the eye and promotes healing

Legend: Comparison of *Ayurvedic* bandaging techniques and modern equivalents with their benefits in wound management. Sushruta's strategies influence modern wound care, particularly infection prevention, scar management, and long-term wound maintenance.

(ii) *Antimicrobial Nanofiber Dressings:* In this, nanofiber dressings like herbal-infused bandages used by Sushruta echo the same idea of antimicrobial uses.
(iii) *Silver-Infused Dressing:* This is aligned with *Ayurvedic* practices using antimicrobial metals, which can provide long-term infection control[40].

4.1 Biocompatibility and Sustainability

Like the present-day concern for biocompatibility and sustainability, Sushruta stresses using natural materials. In place of the materials used by Sushruta, modern alternatives are biodegradable polymers and plant-based adhesives. These advances uphold patient safety and diminish such interventions' adverse effects on the environment[41].

4.2 Sophisticated Applications

Modern biocompatible bandages contain drug delivery systems and pH sensors, which in Sushruta's time were considered medicated bandages infused with healing herbs. Today, such technologies monitor wound healing in real-time and provide targeted treatments, as shown in Table 6[42,43].

4.3 Comparison of *Ayurvedic* and Modern Principles in Wound Healing

The Sushruta Samhita sheds light on wound healing principles, which are impressive compared to modern medicine. Through natural forces, the principles of *Shodhana* and *Ropana* are characteristic of *Ayurveda*. Debridement, antiseptics, and antibiotics, from a contemporary point of view, are employed in modern medicine. There is an emphasis in both the systems mentioned above on infection control, tissue regeneration, and optimal healing environment[44].

4.4 Debridement and Infection Control

In *Ayurveda*, medicated oils [*Taila*] and decoctions with antimicrobial properties from herbs are used to cleanse wounds. Correspondingly, modern antiseptics include iodine and hydrogen peroxide. Sushruta uses alkaline *Kshara*, a caustic material, to purify wounds, corresponding to surgical debridement[45].

4.5 Wound Healing and Tissue Regeneration

Sushruta advised using *Ropana Dravyas*, such as honey and ghee, which are known for their antimicrobial and anti-inflammatory properties. Modern dressings, whether silver-impregnated materials or hydrogel dressings, have replicated the effect by creating a moist and microbe-free environment, therefore favourable for cell proliferation, as listed in Table 7[44,45].

Table 6. Innovations Inspired by Sushruta[42,43]

Traditional Practice	Modern Innovation	Key Features
Cotton [*Karpasa*] Dressings	Hydrogel dressings	Moisture retention, cooling
Herbal-Infused Bandages	Antimicrobial dressings	Infection control
Bark Splints	Biodegradable polymers	Eco-friendly, rigid support
Metal Strips [*e.g.*, Gold]	Silver-infused dressings	Antimicrobial properties
Medicated Bandages	Drug delivery systems	Targeted, sustained medication
Spiral Bandages [*Mandal*]	Elastic wraps	Flexible, adjustable compression

Legend: Sushruta's thoughts and inventions inspire innovation to mend the old with new material science, where wound healing progresses not only in the biomedical or chemical but also in several aspects - resistance to antibiotics, sustainability, and cost-effectiveness.

Table 7. Comparison of *Ayurvedic* and modern wound healing principles[44,45]

Ayurvedic Principle	Modern Equivalent	Application/Use Case
Shodhana [cleansing]	Debridement, antiseptics	Removes necrotic tissue, infection
Ropana [healing]	Antimicrobial dressings, hydrogel	Promotes tissue regeneration
Kshara [alkaline cleansing]	Surgical debridement	Purifies wounds to prevent infection
Medicated oils [Taila]	Antibiotic ointments	Infection control, soothing wounds
Sivana Karma [suturing]	Modern sutures and staples	Closes wounds effectively
Herbal pain relievers	Analgesics	Minimises patient discomfort

Legend: Modern medicine builds upon these ancient principles, enhancing their efficacy with advanced technologies and materials while retaining the core philosophy of wound management.

4.6 Integration of *Anushastra Karma* [Non-Surgical Tools] in Wound Management

The Sushruta Samhita has documented various *Anushastra Karma*, non-surgical tools, and novel methods like *Kshara Sutra*, alkaline thread therapy, and herbal applications. These were devised for diseases requiring minimal invasiveness, including chronic fistulas, abscesses, and wounds that do not heal[46].

4.6.1 Kshara Sutra: Revolutionary Non-surgical Technique

Kshara Sutra is a medicated thread smeared with alkaline substances from herbs. They are still in use today in *Ayurveda* for *Bhagandara* [anal fistula]. Its contemporary equivalents would be catheter-based drug delivery systems, which release medication over time right at the site of involvement[47].

4.7 Case Applications of Sushruta's Bandaging Techniques in Modern Medicine

The ability of Sushruta's bandaging techniques to be applied in modern medicine points out their importance. In particular, *Gophana Bandha*, the chin or barrel bandage, proves pretty effective in managing pressure ulcers and diabetic wounds.

4.7.1 Venous Ulcers

Mandal Bandha, or spiral bandages for venous ulcers, has led to compression wraps that help control oedema and promote healing by improving circulation.

4.7.2 Diabetic Wounds

In today's world, the principle of multi-layer dressing reminds one of Sushruta's methods of layered bandaging, infection care, exudate management, and cushioning[48].

4.8 Surgical and Non-surgical Approaches to Chronic Wounds in *Ayurveda*

Sushruta combined *Chhedana* [excision] surgeries with *Bandhana Karma* to care comprehensively for a patient's wounds. Sushruta's methods were designed to address acute and chronic conditions without causing more complications than necessary.

4.9.1 Surgical Methods

Chedana [excision] by Sushruta, used in removing dead tissue and saponification, is comparable to modern surgical debridement. His focused cuts also avoided tearing the *Marma*, crucial structures, resulting in fewer complications during recovery.

4.9.2 Non-Surgical Methods

Herbal-infused bandages and *Pichu* [plugs] were used to control infection and aid wound healing, similar to antibiotic ointments and hydrocolloid dressings today, as shown in Table 8[49,50].

5. Future Directions and Limitations

Sushruta's bandaging techniques, or *Bandhana Karma*, can be well integrated with modern medical technologies to present a broad scope for innovation in wound care. It further looks at integrating ancient principles with results from cutting-edge research in developing holistic, sustainable, cost-effective solutions for managing acute and chronic wounds. This approach mainly addresses challenges such as antimicrobial resistance, accessibility in low-resource settings, and environmental sustainability[51].

5.1 Challenges and Limitations

Despite the potential of such techniques, like those of Sushruta, their implementation in modern medicine is

Table 8. Surgical and non-surgical approaches[49,50]

Approach [*Ayurvedic* term]	Modern equivalent	Key benefits
Chhedana [excision]	Surgical debridement	Removes necrotic tissue
Kshara Sutra	Drug-infused catheters	Sustained medication delivery
Pichu and *Patra* [cotton/leaves]	Hydrocolloid dressings	Absorbent, infection control
Taila [medicated oils]	Antibiotic ointments	Reduces infection and inflammation
Anuloma Sutra [tying threads]	Surgical threads	Holds tissue together
Bandhana Karma [bandaging]	Compression and protective wraps	Stabilises wounds

Legend: Comparison of *Ayurvedic* surgical and non-surgical approaches with their modern equivalents and key benefits in wound care.

far from straightforward. The approach must still include the necessary clinical validation to be widely adopted as an evidence-based strategy. Furthermore, in rural and low-resource areas, the technical advancements that stem from the *Ayurvedic* foundations of this treatment, like AI-enabled bandages, have scaling problems. Notwithstanding these drawbacks, Sushruta's work contributes to a distinctive, holistic and sustained wound healing method. Healthcare practitioners can create creative, affordable solutions to address the problem of global health inequities by fusing traditional knowledge with contemporary technologies[52].

6. Discussion

One of the oldest known books, which is over two thousand years in existence, yet it is still the cornerstone of *Ayurvedic* medicine that provides considerable knowledge about surgical practices and wound management, is the Sushruta Samhita. This paper deals with the relevance of Sushruta's bandaging techniques [*Bandhana Karma*] in the present medical scene, specifically concerning application in trauma and non-trauma cases, material science, and holistic patient care[53].

6.1 Relevance of Sushruta's Bandaging Techniques

Sushruta's 14 bandaging techniques are particular and varied in meeting anatomical and pathological needs. *Swastika Bandha* for the joints corresponds to contemporary orthopaedic care; *Mandal Bandha* - spiral compression therapy for venous ulcers. These techniques demonstrate excellent comprehension of biomechanics, wound dynamics instability, pressure modulation, and infection control[54]. Sushruta's practices emphasised the comfort of the patient and the careful management of psychological outlooks. The modern trend is only recently venturing down the route of personalised medicine, which incorporates the holistic approach of all these practices. These techniques apply to chronic ulcers, fractures, and postsurgical wounds, assuming that minimal pain and functional support form the cornerstone of these devices or methods[55].

6.2 Modern Innovations and Traditional Materials

Sushruta's use of cotton [*Karpasa*], silk, and bark emphasises biocompatibility and eco-friendliness. Their modern counterparts, hydrogel dressings and nanofiber-based materials, enhance their properties with moisture retention, antimicrobial activity, and biodegradability. This integration between a traditional material science approach and its modern counterpart may represent the integrative medicine approach in general[56].

Nanotechnology in itself is a giant leap forward. *Ayurvedic* herbs like turmeric and neem combined with nanofiber dressings would give healthcare providers the promise of sustained antimicrobial effects, accelerate healing, and calm wounds. It mirrors the concept of Sushruta's medicated bandages, wherein treatment and protection became paired properties[57].

6.3 Chronic Wounds

The applications of Sushruta's bandage techniques do not stop at trauma; they extend into non-traumatic conditions, especially in chronic conditions such as diabetic ulcers or venous insufficiency. Most current health delivery systems must be equipped for problems plaguing cases involving infection, delay in healing, and antibiotic resistance, among others. Therefore, Sushruta's principles, such as individually adapted bandaging and medicated dressings, offer a structure to deal with such problems in a sustainable and patient-friendly min vanner[58].

6.4 Limitations

Limited clinical evidence. One of the chief limitations of this paper is that no clinical evidence can be directly applied to prove the use of Sushruta's bandaging techniques in combination with the wound care materials of today. Although theoretical considerations have pointed out significant correlations between the methods applied in the ancient and modern eras, the absence of empirical research or clinical trials makes the validation of the efficacy and practicability of such combined techniques in real-world healthcare practice impossible. Further clinical research needs to be conducted to prove the real-world efficacy of Sushruta's technique in combination with modern wound care technology.

7. Conclusion

The medical texts written by Sushruta comprise timeless principles of wound care and bandaging, which are still

valid today. His 14 bandaging techniques, *Bandhana Karma*, are particular to a certain kind of injury and anatomical portions and show the great awareness of Sushruta through biomechanics, healing dynamics, and patient comfort. His use of biocompatible materials such as cotton, *Karpasa*, and bark already matches the emerging trend of using sustainable and environmentally friendly methods in medicine. This clearly shows how Sushruta's methods can be incorporated into current integration with innovations such as hydrogels, nanotechnology, or AI-enabled bandages while retaining the relevance of *Ayurvedic* practices. Specifically, Sushruta's methods have been used to address critical challenges in wound care, such as infection control, chronic wound management, and resource limitations for most underprivileged regions. However, clinical validation requirements and scale-up capabilities limit their application in modern medicine. Only through collaborative research can this traditional wisdom be synthesised with scientific rigour to develop integrative healthcare solutions that could look beyond these limitations. Finally, Sushruta's legacy is a guideline for sustainable, holistic, patient-centred wound care. Using his insights and applying them to modern technologies can make health systems face global health challenges while preserving the delivery of principles of *Ayurvedic* medicine. This integrated approach alone pays homage to the past but promises innovative and equitable health for the future.

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9. Author Contribution

Dr. Shubham Patil created the research design, formulated the study, critically appraised the literature, and drafted the manuscript. Dr. Sheetal Asutkar (Professor and HOD) provided expertise to Shalyatantra's clinical principles, assisted in making the manuscript better, and assisted in integrating ancient practices into modern wound care. All authors have read and agreed to the published version of the manuscript.

10. References

1. Sood A, Granick MS, Tomaselli NL. Wound dressings and comparative effectiveness data. Adv Wound Care [New Rochelle]. 2014; 3(8):511-529. https://doi.org/10.1089/wound.2012.0401 PMid:25126472 PMCid:PMC4121107
2. Das S, Bhattacharya P. Alkaline therapies in wound care: A comparison of Sushruta's Kshara with modern antiseptics. J Adv Surg Sci. 2021; 15(2):68-76.
3. Patel M, Sharma D. Sushruta's approach to wound healing: Relevance in modern clinical practices. Asian J Med Hist. 2023; 9(3):45-58.
4. Tiwari VP, Chaudhary A. Revisiting ancient surgical techniques of Sushruta. J Indian Med Assoc. 2021; 119(3):25-30.
5. Verma SK, Kharbanda M. Role of *Bandhana Karma* and its relevance in contemporary surgery. *Ayurveda* Res Pract. 2020; 12(3):19-27.
6. Joshi FP. Classical surgical insights of Sushruta and their interpretations in modern medicine. JREIM-Ayush J. 2024; 6(2):45-52.
7. Kumar V, Patel R, Chaudhary S. Holistic healing and surgical innovations in Sushruta Samhita. Indian J Surg. 2022; 84(5):901-904. https://doi.org/10.1007/s12262-022-03578-y
8. Singh RK, Pandey A, Sharma N. Sushruta's legacy in surgical practices: Ancient techniques for modern medicine. Cureus. 2023; 15(9).
9. Bolton LL, Monte K, Pirone LA. Moisture and healing: Beyond the jargon. Ostomy Wound Manag. 2000; 46(1A Suppl):51S-62S.
10. Lansdown AB. Silver in health care: Antimicrobial effects and safety in use. Curr Probl Dermatol. 2006; 33:17-34. https://doi.org/10.1159/000093928 PMid:16766878
11. Bhattacharya S. Wound healing through the ages. Indian J Plast Surg. 2012; 45(2):177-179. https://doi.org/10.4103/0970-0358.101255 PMid:23162212 PMCid:PMC3495363
12. Dev S, Pandey SK, Sharma S, *et al.* Surgical procedures in Sushruta Samhita: Significance for modern medicine. Ayushdhara. 2015; 1(1):7-12.
13. Kumar A, Sharma R. Bandaging techniques in Sushruta Samhita: A re-evaluation for clinical use. AYUHOM. 2021; 10(4):40-49.

14. Bagde M, Pujari S, More N. Surgical concepts in ancient *Ayurvedic* texts: A perspective. World J Pharm Pharm Sci. 2018; 7(18):1085-1092.
15. Mishra B. Historical evolution of surgical knowledge: Lessons from *Ayurveda*. Res Tradit Med. 2020; 6(1):35-40.
16. Lineaweaver W, Howard R, Soucy D, *et al.* Topical antimicrobial toxicity. Arch Surg. 1985; 120:267-270. https://doi.org/10.1001/archsurg.1985.01390270007001 PMid:3970664
17. Li N, Liu W, Zheng X, *et al.* Antimicrobial hydrogel with multiple pH-responsiveness for infected wounds. Nano Res. 2024; 17:1043-1055.
18. Sosa-Herrera J, Vázquez-Lasa B, Saiz E, *et al.* Advances in alginate-based hydrogels for wound healing. Biomacromolecules. 2023; 24(5):1332-1348.
19. Leung CM, Dhand C, *et al.* Magnesium mineralized antimicrobial nanofiber dressings for wound healing. Biomater Sci. 2020; 8(12):3454-3471. https://doi.org/10.1039/D0BM00530D PMid:32420550
20. Ahmed R, Haleem A, Qadri T. Biopolymer-based electrospun wound dressings for healing. Polymers Adv Technol. 2021; 32(5):987-1001.
21. Schultz GS, Sibbald GR, Falangna V, Ayello EA, Dowsett C, Harding K, *et al.* Wound bed preparation: A systematic approach. Wound Repair Regen. 2003; 11(1):1-28. https://doi.org/10.1046/j.1524-475X.11.s2.1.x PMid:12654015
22. Bradley M, Cullum N, Nelson EA, *et al.* Systematic reviews of wound care management: Dressings and topical agents. Health Technol Assess. 1999; 3:1-35. https://doi.org/10.3310/hta3172 PMid:10683589
23. Rajendran VK, Hafeez AR, *et al.* Role of nanofiber dressings in chronic wound care. Int J Nanomedicine. 2022; 17:1121-1134.
24. Gu R, Zhou H, Zhang Z, Lv Y, Pan Y, Li Q, *et al.* Research progress related to thermosensitive hydrogel dressings. Nanoscale Adv. 2023; 5:6017-6037. https://doi.org/10.1039/D3NA00407D PMid:37941954 PMCid:PMC10629053
25. Liu Y, Fan Y, Xie H, *et al.* Nanotechnology-based wound dressings for enhanced tissue regeneration. Mater Today Bio. 2023; 20:101323.
26. Fang J, Zhu Y, Bao W, *et al.* Sprayable hydrogel-based dressings for wound coverage and healing. MDPI Polymers. 2022; 14(5):1234.
27. Toh YC, Lim F, Barathi VA, *et al.* Role of chitosan and alginate in hydrogel wound dressings. J Biomed Mater Res Part B Appl Biomater. 2021; 109(5):1338-1348.
28. Wang B, *et al.* Lignin-based hydrogels for wound healing and controlled drug delivery. J Bioresour Bioprod. 2024; 9(10):31-42.
29. Romero-Montero A, Labra-Vázquez P, del Valle LJ, Puiggalí J, García-Arrazola R, Montiela C, *et al.* Development of antimicrobial hydrogel/nano-electrospun wound dressing. RSC Adv. 2020; 10:30508-30518. https://doi.org/10.1039/D0RA05935H PMid:35516054 PMCid:PMC9056286
30. Gupta R, Sharma S, Dwivedi M. Antimicrobial dressings loaded with plant extracts for wound care. J Biomed Mater Res Part A. 2022; 110(8):2321-2333. https://doi.org/10.1002/jbm.a.37524 PMid:36866394
31. Ramakrishna S, Lee SM, Lim FP, *et al.* Innovative nanofiber systems for infection-controlled wound healing. J Mech Behav Biomed Mater. 2023; 140:105495.
32. He JH, Guo BL. Functional hydrogels as wound dressings to enhance wound healing. ACS Nano. 2021; 15:12687-12722. https://doi.org/10.1021/acsnano.1c04206 PMid:34374515
33. Armstrong DG, Lavery LA. Diabetic foot ulcers: prevention, diagnosis, and classification. Am Fam Physician. 1998; 57(6):1325-1332.
34. Yazdanpanah L, Nasiri M, Adarvishi S. Literature review on managing diabetic foot ulcer. World J Diabetes. 2015; 6(1):37-53. https://doi.org/10.4239/wjd.v6.i1.37 PMid:25685277 PMCid:PMC4317316
35. Pendsey SP. Understanding diabetic foot. Int J Diabetes Dev Ctries. 2010; 30(2):75-79. https://doi.org/10.4103/0973-3930.62596 PMid:20535310 PMCid:PMC2878694
36. Zhang P, Lu J, Jing Y, Tang S, Zhu D, Bi Y. Global epidemiology of diabetic foot ulceration: A systematic review and meta-analysis. Ann Med. 2017; 49(2):106-116. https://doi.org/10.1080/07853890.2016.1231932 PMid:27585063
37. Singh N, Armstrong DG, Lipsky BA. Preventing foot ulcers in patients with diabetes. JAMA. 2005; 293(2):217-228. https://doi.org/10.1001/jama.293.2.217 PMid:15644549
38. Bus SA, van Netten JJ, Lavery LA, Monteiro-Soares M, Rasmussen A, Jubiz Y, *et al.* IWGDF guidance on the prevention of foot ulcers in at-risk patients with diabetes. Diabetes Metab Res Rev. 2020; 36(S1). https://doi.org/10.1002/dmrr.3270 PMid:31957213
39. Wei Z, Xu T, Wang C, Liu S, Zhang W, Sun J, *et al.* A hydrogel-functionalized silver nanocluster for bacterial-infected wound healing. Nanoscale. 2024; 16(16):10656-10662. https://doi.org/10.1039/D4NR01447B PMid:38758021
40. Yue K, Trujillo-de Santiago G, Alvarez MM, Tamayol A, Annabi N, Khademhosseini A. Synthesis, properties, and biomedical applications of gelatin methacryloyl [GelMA] hydrogels. Biomaterials. 2015; 73:254-271. https://doi.org/10.1016/j.biomaterials.2015.08.045 PMid:26414409 PMCid:PMC4610009
41. Li J, Zhang Y, Shen J, *et al.* Multifunctional biomimetic hydrogel dressing provides anti-infection treatment and improves immunotherapy by reprogramming the infection-related wound microenvironment. J Nanobiotechnology. 2021; 19:52.
42. Guo B, Ma PX. Conducting polymers for tissue engineering. Biomacromolecules. 2018; 19(6):1764-1782. https://doi.org/10.1021/acs.biomac.8b00276 PMid:29684268 PMCid:PMC6211800

43. Kamoun EA, Kenawy ER, Chen X. A review on polymeric hydrogel membranes for wound dressing applications: PVA-based hydrogel dressings. J Adv Res. 2017; 8(3):217-233. https://doi.org/10.1016/j.jare.2017.01.005 PMid:28239493 PMCid:PMC5315442
44. Sharma A, Yadav P. Wound management in *Ayurveda*: A holistic approach. Int J Res Anal Rev. 2022; 9(1):45-52.
45. Mishra S, Rajan S. Biocompatible wound dressings: Insights from *Ayurveda* and material science. J Ethnopharmacol. 2022; 280:114235.
46. Sharma RK, Dash B. *Charaka* Samhita: Text with English translation and critical exposition based on Cakrapani Datta's *Ayurveda* Dipika. Varanasi: Chaukhambha Sanskrit Series Office; 1998.
47. Dwivedi AP, Upadhyay AK. The efficacy of *Kshara Sutra* therapy in Bhagandara [Fistula-in-ano] is a comprehensive review. Ayu. 2021; 42(3):209-214.
48. Singh AK, Goel RK. Role of *Kshara Sutra* in managing anorectal disorders: A systematic review. J *Ayurveda* Integr Med. 2015; 6(4):241-249.
49. Jain A, Agarwal SK. A prospective observational study comparing *Ksharsutra*, Fistulectomy, and LIFT in managing fistula-in-ano. BMC Surg. 2020; 20(1):293.
50. Timmerman C, Barlow J, White G. Methods for chronic wound research: A scoping systematic review of the recommendations, guidelines, and standards. Wound Pract Res. 2017; 25(2):72-79.
51. Patel B, Kothari V, Acharya N. Mainstreaming traditional practices for wound management. Wound Healing Research. Springer Singapore; 2021. https://doi.org/10.1007/978-981-16-2677-7_7
52. Jones C, Harding KG. Nanotechnology for wound therapy: A review. J Tissue Viability. 2020; 29(4):200-206.
53. Gupta A, Singh S, Kothari P. Herbal medicine: Revitalizing the ancient tradition. J Altern Complement Med. 2021; 27(10):872-880.
54. Pandey A, Verma S. Challenges and scope in integrating *Ayurveda* with nanotechnology for wound healing. Int J *Ayurveda* Res. 2022; 13(2):67-74.
55. Agarwal R, Shukla HS. Ancient principles of wound care in modern-day medical practice. J Ethnopharmacol. 2020; 259:112914.
56. Mehta V, Singh B. Revisiting traditional wound care remedies for modern application. Phytomedicine. 2021; 81:153407.
57. Khan MS, Ahmad I. Current approaches to improve wound healing: Insights into emerging nanotechnologies. Front Med. 2022; 9:808514.
58. Roy S, Khanna S, Sen CK. Wound care technologies: An integrated approach. Adv Wound Care. 2019; 8(12):665-678.