

Review Article

Skin Cancer: Epidemiology, Risk Factors, Molecular Pathogenesis, Non-Invasive Diagnosis and Contemporary Therapeutic Strategies

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ABSTRACT

Skin cancer comprises a heterogeneous group of malignancies with markedly different biological behavior, ranging from locally destructive but usually slow-growing basal cell carcinoma (BCC) and potentially metastatic cutaneous squamous cell carcinoma (cSCC) to melanoma, the most aggressive major cutaneous malignancy. The attached thesis identifies ultraviolet (UV) radiation as the principal modifiable driver and reviews the contributions of phenotype, genetic susceptibility, immunosuppression, chronic inflammation and carcinogen exposure. It also describes the transition from conventional clinical examination and biopsy toward dermoscopy, total-body photography, reflectance confocal microscopy, ultrasound, spectroscopy, electrical bio-impedance, tape stripping, multispectral imaging and computer-assisted analysis. This review updates that framework using contemporary evidence and emphasizes the clinical integration rather than the replacement of histopathology by emerging technologies. UV-associated DNA damage, oxidative stress and disruption of tumor-suppressor and oncogenic signaling form the biological basis of carcinogenesis. BCC is strongly associated with aberrant Hedgehog signaling, whereas melanoma commonly involves MAPK-pathway alterations including BRAF and NRAS. Treatment is stage- and subtype-dependent: surgery remains the principal curative treatment for most localized tumors, while advanced melanoma is managed increasingly with immune-checkpoint inhibitors and molecularly targeted therapy; advanced BCC and cSCC also have effective systemic targeted and immune-based options. Artificial intelligence (AI) can augment image interpretation, but external validation, dataset diversity, clinical workflow integration and explainability remain important limitations. Prevention through UV avoidance, protective clothing, shade and broad-spectrum sunscreen is a high-value population strategy. A future model of skin-cancer care will combine risk-adapted surveillance, multimodal non-invasive imaging, pathology and molecular profiling with individualized treatment and long-term prevention.

Keywords: Skin Cancer; Melanoma; Basal Cell Carcinoma; Cutaneous Squamous Cell Carcinoma; Ultraviolet Radiation; Dermoscopy; Artificial Intelligence; Immunotherapy; Targeted Therapy; Prevention.

Introduction

Skin cancer is among the most common malignancies worldwide and represents a major public-health challenge because incidence is influenced by environmental exposure, phenotype, genetics, occupational behavior and increasing longevity. The thesis distinguishes melanoma from non-melanoma skin cancers (NMSC), principally BCC and cSCC, and emphasizes that although BCC and cSCC are more frequent, melanoma has a disproportionately high potential for metastasis and mortality [1].

GLOBOCAN 2022 recorded 1,234,533 new cases of NMSC and 69,416 deaths, although ascertainment of NMSC remains incomplete in many settings [2]. Melanoma is less common than NMSC but contributes substantially to skin-cancer mortality; contemporary European consensus guidance describes cutaneous melanoma as the most dangerous major skin tumor and emphasizes dermoscopic confirmation of clinically suspicious lesions [3].

This review synthesizes the thesis with updated literature on epidemiology, risk assessment, carcinogenesis, clinical presentation, diagnosis, treatment, prevention and emerging technologies. Particular attention is given to non-invasive diagnosis and AI because these areas are rapidly evolving, while their clinical limitations are often underemphasized.

Epidemiology and Clinical Classification

The principal clinicopathological categories considered are melanoma, BCC and cSCC. The thesis reports that NMSC constitutes the overwhelming majority of diagnosed skin malignancies and that BCC is generally less aggressive than cSCC, whereas melanoma has a much greater propensity for dissemination [4]. Contemporary epidemiological comparisons should be interpreted cautiously because BCC and cSCC are incompletely registered in many national cancer registries.

Melanoma arises from melanocytes and includes superficial spreading, nodular, lentigo maligna and acral lentiginous patterns. The thesis discusses the rapid vertical growth of nodular melanoma, the chronic sun-exposure association of lentigo maligna melanoma, and the acral distribution of acral lentiginous melanoma [5].

BCC originates from basal keratinocytic lineage and is characterized by local tissue invasion with relatively uncommon distant metastasis. cSCC arises predominantly from keratinocytes and has greater metastatic potential, particularly when tumors are high-risk by location, size, depth, differentiation or host factors. The thesis also identifies uncommon NMSC entities, including Merkel cell carcinoma and other rare tumors, but these are beyond the central scope of this review [6].

Table 1: Major clinical distinctions among the principal skin cancers.

Feature	Melanoma	BCC	cSCC	Clinical implication
Cell of origin	Melanocyte	Basal keratinocytic lineage	Squamous keratinocyte	Histopathology confirms lineage
Typical behavior	High metastatic potential	Locally invasive; metastasis uncommon	Locally invasive; metastatic risk varies	Risk stratification guides management
UV relationship	Intermittent/intense exposure important	Cumulative and intermittent exposure	Strong cumulative UV association	Protection is relevant to all
Clinical clues	New/changing pigmented lesion; ABCDE	Pearly/waxy or persistent lesion	Scaly/crusted plaque, nodule or sore	Changing lesions warrant assessment
Definitive diagnosis	Biopsy + histopathology	Biopsy + histopathology	Biopsy + histopathology	Imaging generally remains adjunctive

Risk Factors and Risk Assessment

UV radiation is the most important modifiable risk factor for melanoma and NMSC. The thesis describes UVA as penetrating more deeply and promoting oxidative injury, while UVB produces direct DNA photoproducts including pyrimidine dimers. Both pathways contribute to carcinogenesis [7].

Occupational solar exposure is also relevant; WHO/ILO evidence supports an association between occupational solar UV exposure and malignant skin cancer [8].

Host factors include lighter phototypes, tendency to burn, light hair and eyes, multiple or atypical nevi, family history and inherited susceptibility. Immunosuppression is a major risk modifier,

particularly for cSCC after solid-organ transplantation. Chronic wounds, scars, inflammatory dermatoses and carcinogen exposure such as arsenic may also contribute. The thesis summarizes type-specific risk factors and notes movement toward individualized risk scores [9].

Risk assessment should therefore be multidimensional. A practical framework considers cumulative and intermittent UV exposure, occupational history, phenotype, previous skin cancers, number and morphology of nevi, family history, immunosuppression and relevant genetic syndromes. High-risk individuals benefit from personalized surveillance rather than indiscriminate testing of the general population.

Molecular Pathogenesis

Skin carcinogenesis is a multistep process involving DNA damage, defective repair, clonal selection, altered cell-cycle control, immune escape and remodeling of the tumor microenvironment. UVB directly produces cyclobutane pyrimidine dimers, while UVA contributes substantially through reactive oxygen species. Persistent damage generates mutational signatures and disrupts tumor suppressor and oncogenic pathways.

In cSCC, TP53 alteration is a major molecular event. In BCC, constitutive activation of Hedgehog signaling, most commonly through PTCH1 or related pathway alterations, is central to tumor development. Melanoma is molecularly heterogeneous; activating alterations in BRAF or NRAS can drive MAPK signaling, while CDKN2A, NF1, KIT and other genes may contribute in selected tumors. The thesis identifies p53/PTCH abnormalities in BCC and BRAF/NRAS-related signaling in melanoma as important examples [10].

The clinical significance of this heterogeneity is substantial. Molecular testing can identify actionable alterations and support selection of targeted therapy, but genomic information must be interpreted together with stage, anatomical site, histology, tumor burden, comorbidity and prior treatment. Skin-cancer management is therefore increasingly precision-oriented.

Clinical Manifestations and Early Warning Features

Melanoma commonly presents as a new lesion or a changing pre-existing pigmented lesion. The ABCDE framework—Asymmetry, Border irregularity, Color variation, Diameter and Evolution—remains useful for public awareness, while the 'ugly duckling' sign can identify a lesion that differs from a patient's other nevi.

The American Cancer Society emphasizes change in size, shape, color or texture [11].

BCC may present as a pearly, translucent or waxy papule, a persistent ulcer, or a lesion that repeatedly crusts or bleeds. cSCC may appear as a rough or scaly patch, keratotic nodule, wart-like lesion or non-healing sore [12]. These features are not diagnostic in isolation because benign and premalignant lesions can mimic malignancy.

Early recognition matters because treatment is most effective before substantial local invasion or metastatic spread. The thesis similarly emphasizes persistent lesions, changing moles, bleeding, ulceration and non-healing sores as triggers for assessment [13].

Diagnosis: From Clinical Examination to Multimodal Imaging

Diagnosis begins with history and full skin examination, followed by dermoscopy for lesions requiring closer assessment. Histopathological examination of a biopsy remains the reference method for definitive diagnosis in most suspicious lesions. The thesis identifies physical examination, dermoscopy, biopsy and histopathological evaluation as core approaches [14].

Dermoscopy improves visualization of pigment networks, vascular structures and architectural patterns that are not readily visible to the unaided eye. It is valuable for pigmented lesions and can reduce unnecessary biopsies when interpreted by experienced clinicians. The thesis also describes automated border detection, image segmentation and smartphone-linked systems [15].

Non-invasive modalities described in the thesis include high-frequency ultrasound, total-body photography, reflectance confocal microscopy (RCM), terahertz spectroscopy, fluorescence spectroscopy, Raman spectroscopy, tape stripping, multispectral imaging, thermography and electrical bio-impedance [16]. These techniques provide complementary information but differ in availability, operator dependence, evidence maturity and ability to replace biopsy.

RCM can provide near-histological cellular detail in vivo and has been described as a 'virtual biopsy' approach. The thesis notes its ability to examine living skin with minimal preparation [17]. Raman and fluorescence spectroscopy provide biochemical information, while terahertz methods explore differences in tissue absorption and dielectric properties. These approaches remain promising but are not yet interchangeable with routine histopathology across all settings.

Table 2: Diagnostic technologies and their current clinical role.

Technology	Primary information	Strengths	Important limitations
Clinical examination	Morphology, symptoms, distribution	Low cost; accessible	Subjective; subtle lesions may be missed
Dermoscopy	Pigment and vascular architecture	Improves lesion assessment	Operator dependent
Total-body photography	Longitudinal change	Useful with multiple nevi	Time, cost, image quality
RCM	Cellular morphology	Non-invasive, near-histological detail	Limited depth; cost/expertise
High-frequency ultrasound	Tumor depth/structure	Non-invasive	Limited specificity; operator dependent
Raman/fluorescence/THz	Biochemical/optical signatures	Potentially objective	Standardization/evidence still developing
Tape stripping	Surface molecular information	Painless adjunct	Sampling depth/validation constraints
AI/image analysis	Pattern recognition	Rapid decision support	Bias, validation, explainability

Artificial Intelligence and Digital Dermatology

AI has become a major area of skin-cancer diagnostics. Deep-learning systems can analyze dermoscopic and clinical photographs, identify suspicious lesions and support classification. Reviews describe applications spanning dermoscopy, total-body systems and smartphone-based analysis, while emphasizing the gap between controlled-dataset performance and proven real-world clinical utility [18].

Systematic evidence suggests promising performance in non-invasive imaging of NMSC, but heterogeneity in datasets and endpoints complicates pooled interpretation. A systematic review identified 44 AI studies involving NMSC imaging and reported favorable overall performance while noting the need for better disease-specific validation. Commercial AI-assisted dermoscopic systems similarly require external validation before routine deployment [19].

The appropriate near-term role of AI is augmentation rather than autonomous replacement. Priorities include representative datasets across skin tones and lesion types, prospective multicenter validation, calibration, transparent error reporting, explainability, privacy and integration with pathology. AI should be evaluated on clinically meaningful outcomes such as unnecessary biopsy reduction, earlier diagnosis, equity and safety.

Management and Contemporary Therapeutic Strategies

Treatment is determined by histological subtype, stage, tumor size and location, recurrence risk, molecular characteristics, patient fitness and goals. For localized BCC and cSCC, surgical excision remains a principal curative approach, with Mohs micrographic surgery especially useful for selected high-risk or anatomically

sensitive tumors. Other local options include curettage and electrodesiccation, cryosurgery, topical therapy and radiotherapy. NCI guidance confirms excision, Mohs surgery, radiation, curettage/electrodesiccation and cryosurgery among established approaches for localized cSCC [20].

Photodynamic therapy is an important tissue-sparing modality for selected superficial NMSC and premalignant lesions. Recent work has explored combinations of 5-aminolevulinic acid photodynamic therapy with differentiation-promoting agents, although lesion size and adequate photosensitizer accumulation remain limitations [21].

Advanced BCC and cSCC have benefited from systemic targeted and immune therapies. Hedgehog-pathway inhibitors are established options for advanced BCC, while immune-checkpoint inhibitors have expanded treatment possibilities for advanced cSCC and other NMSC. Recent reviews describe immunotherapy as a major change in advanced NMSC management [22].

Melanoma management has undergone substantial transformation. Surgical excision remains central for localized disease, while systemic therapy for advanced disease is dominated by immune-checkpoint inhibition and, in molecularly selected patients, MAPK-pathway targeted therapy. The thesis discusses BRAF-targeted treatment, tumor-infiltrating lymphocyte therapy, therapeutic vaccination, oncolytic viral therapy, Toll-like receptor agonists, electrochemotherapy and radiotherapy as evolving or adjunctive strategies [23]. NCI guidance continues to frame treatment according to stage and evidence strength [24].

The future therapeutic landscape is increasingly multimodal. Molecular profiling can identify targetable

alterations; immunotherapy can generate durable responses in selected patients; and local modalities can provide control of limited disease. Immune-related

adverse events, resistance, cost and unequal access remain major challenges.

Table 3: Treatment strategy by clinical setting.

Setting	Established approaches	Emerging options	Key considerations
Localized BCC	Excision/Mohs; selected topical/destructive therapies; radiotherapy	PDT and optimized field therapies	Site, recurrence risk, cosmesis
Localized cSCC	Excision/Mohs; selected radiation/destructive approaches	Adjuvant/systemic therapy for high-risk disease	Depth, differentiation, perineural/nodal risk
Localized melanoma	Wide excision ± sentinel-node assessment; stage-based adjuvant therapy	Risk-adapted systemic therapy	Breslow thickness, ulceration, nodal/molecular status
Advanced melanoma	Immune-checkpoint therapy; BRAF/MEK therapy when indicated	TIL therapy, vaccines, oncolytic approaches	Durability, toxicity, resistance
Advanced BCC/cSCC	Hedgehog inhibition for selected BCC; immune-checkpoint therapy	Combination/neoadjuvant/adjuvant strategies	Prior local therapy and access

Natural Products and Complementary Research

The thesis notes increasing interest in herbal medicines and naturally derived compounds because of reported antioxidant, anti-inflammatory and anticancer activities. This is scientifically relevant because oxidative stress, inflammatory signaling and DNA damage are components of cutaneous carcinogenesis. However, promising in-vitro or animal findings should not be presented as equivalent to clinical efficacy.

Natural compounds such as polyphenols have been investigated experimentally for effects on oxidative stress, inflammatory mediators, cell-cycle regulation and apoptosis. Major translational limitations include variable composition, bioavailability, pharmacokinetics, formulation, target exposure and lack of adequately powered randomized trials for many proposed indications. Natural products should therefore be positioned as a research direction rather than a substitute for evidence-based oncology.

Prevention, Screening and Follow-Up

Prevention offers the greatest opportunity to reduce population burden. The American Academy of Dermatology recommends shade, sun-protective clothing and broad-spectrum, water-resistant sunscreen with SPF 30 or higher; avoidance of indoor tanning is also recommended [25]. These measures should be combined rather than treated as mutually exclusive.

Behavioral interventions are particularly important for children, outdoor workers and individuals with previous skin cancer. Public-health programs should promote practical UV-protection behavior, recognition

of suspicious lesions and timely referral. The thesis similarly identifies prevention, awareness, screening and early intervention as essential components of disease control [26].

Routine population-wide screening remains nuanced because benefit, false positives, overdiagnosis and resource use vary by setting. Risk-adapted surveillance is more defensible for individuals with previous melanoma/NMSC, numerous or atypical nevi, strong family history, marked UV exposure or immunosuppression. Follow-up should address recurrence, new primary tumors, treatment adverse effects and long-term sun protection.

Current Challenges and Future Directions

Despite major advances, barriers include delayed presentation, unequal access to dermatology and pathology, limited NMSC registration, treatment cost, therapeutic resistance and underrepresentation of diverse skin tones in diagnostic datasets. The thesis specifically highlights late diagnosis, limited specialized services, high treatment costs and resistance as persistent challenges, particularly in low- and middle-income regions [27,28].

Future progress is likely to depend on integration rather than replacement. Multimodal imaging could combine dermoscopy, RCM, optical/spectroscopic signals and longitudinal photography; AI could assist triage and pattern recognition; molecular pathology could refine diagnosis and therapy selection; and teledermatology could extend specialist expertise to underserved areas. Prospective studies should measure

patient outcomes, diagnostic delay, unnecessary biopsy rates, equity and cost-effectiveness.

Therapeutic research should prioritize mechanisms of resistance and rational combinations. In melanoma, immunotherapy and targeted therapy have changed survival expectations but are not universally effective. In NMSC, immune-based treatments have expanded options for advanced disease, while Hedgehog

inhibition provides a biologically rational option for selected advanced BCC [29,30].

Prevention science should also improve UV exposure measurement, occupational protection, risk prediction and public-health communication. Responsible AI development must ensure that gains in accuracy do not widen disparities between populations represented and underrepresented in training data.

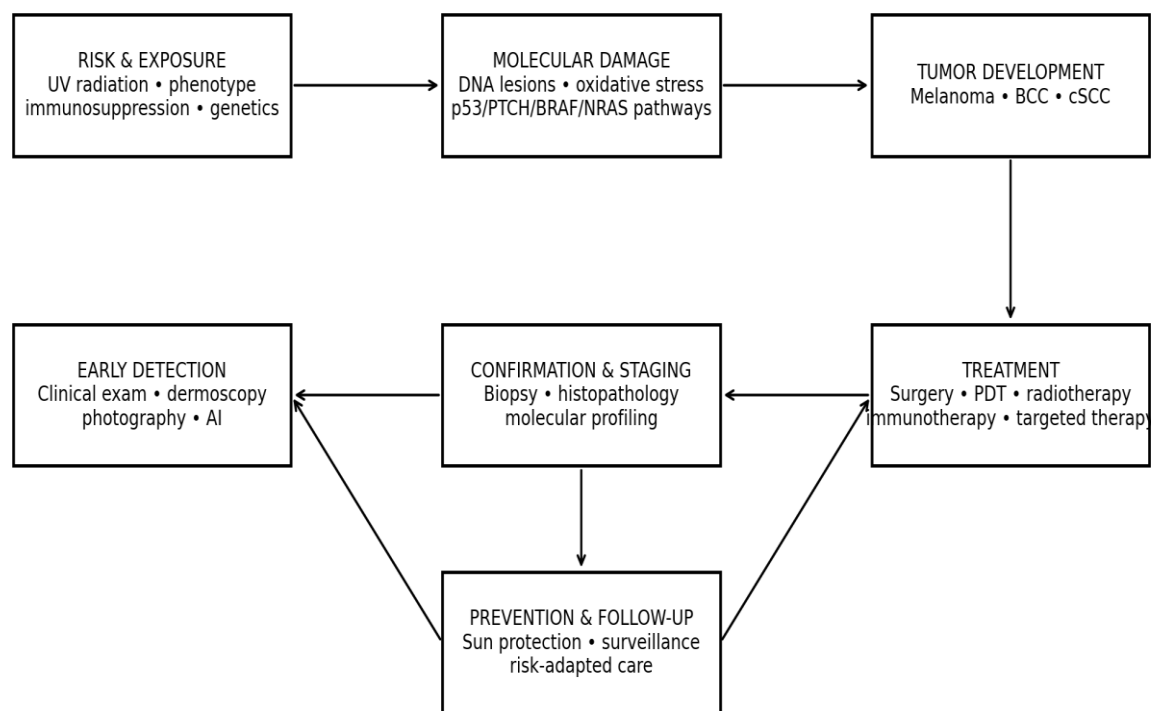


Figure 1: Integrated Clinical Framework.

Conclusion

Skin cancer is a biologically heterogeneous group of malignancies in which prevention, early recognition, accurate diagnosis and stage-appropriate treatment are interdependent. The thesis provides a broad foundation covering classification, risk factors, pathogenesis, non-invasive diagnostic technologies and treatment; contemporary literature strengthens this framework by clarifying the clinical maturity of emerging technologies and the expanding role of systemic therapy. UV exposure remains the principal modifiable risk factor, but phenotype, genetics, immunosuppression and environmental exposures shape individual risk. Dermoscopy and histopathology remain central to diagnosis, while RCM, spectroscopy, total-body photography and AI are increasingly valuable adjuncts. Surgery continues to cure most localized disease, whereas immunotherapy and molecularly targeted therapy have transformed advanced melanoma and expanded options for

advanced NMSC. Future progress will depend on equitable prevention, validated multimodal diagnostics, precision treatment and long-term surveillance. The most clinically useful model is an integrated pathway linking prevention, risk assessment, imaging, pathology, molecular characterization and individualized therapy.

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Conflict of Interest

None declared.

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