

MASTER'S THESIS

DECODING CUTANEOUS GENE SIGNATURES: A BIOINFORMATIC INVESTIGATION
INTO MELANOMA, SKIN PATHOPHYSIOLOGY, AND THE M PROTEIN OF
STREPTOCOCCUS PYOGENES

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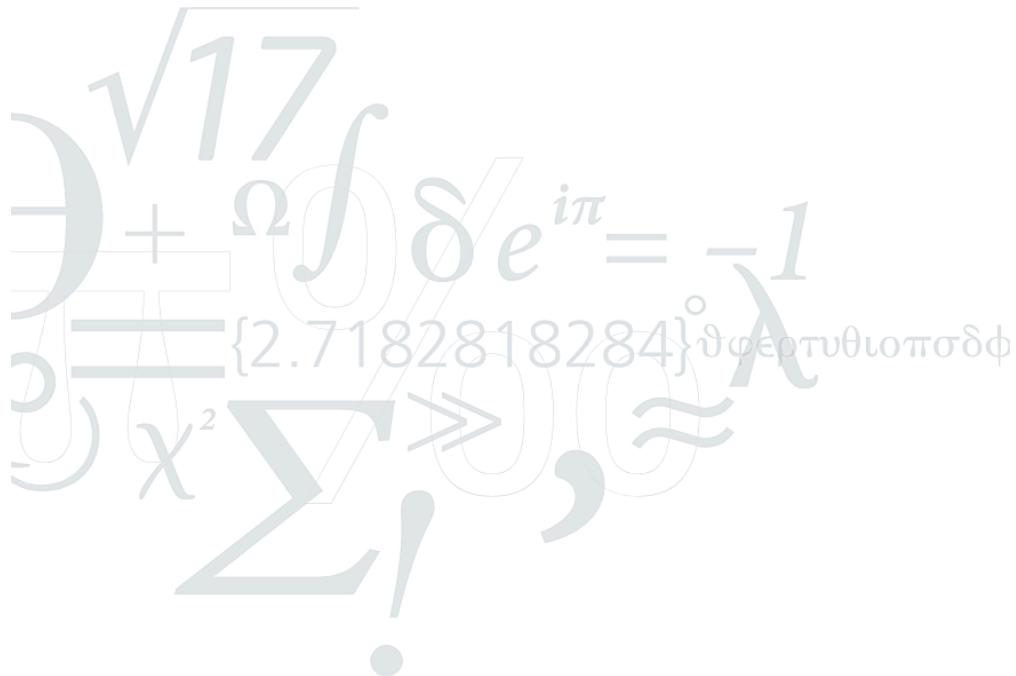
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STATEMENT OF THESIS ORIGINALITY

Declaration of Authorship

I, Miss Oriade Latifah Simpson, hereby declare that the present master's thesis is my own original work and has been written independently. This thesis has not been submitted, either in whole or in part, for the award of any academic degree or qualification at any other institution.

All sources of information and ideas that are not my own have been appropriately acknowledged and referenced, including AI tools¹. I affirm that this work complies with the ethical and academic standards required for submission at the Technical University of Denmark.

This thesis is submitted in partial fulfilment of the requirements for the Master's Programme at the Department of Health Technology, Technical University of Denmark.

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List of Tables

1	(Table of Top 20 Significantly Up-regulated Genes)	28
2	(Table of Top 20 Significantly Down-regulated Genes)	28
3	(ssGSEA Enrichment Summary)	37
4	(ESTIMATE Score Comparison: Melanoma vs Nevus)	39
5	(Table of <i>Streptococcus pyogenes</i> genomes)	40
6	(Table of <i>Streptococcus pyogenes</i> emm genes) <i>Streptococcus pyogenes</i> emm gene for M protein, complete cds of various strains – Collection Date: 15-JAN-2014	40
7	(Outgroup: <i>Streptococcus pyogenes</i> emm50 type - emm gene for M protein, partial cds. of various strains – Collection Date: 26-JUN-2013	41
9	(Tree Statistics from the Consensus Tree)	50

List of Figures

1	AI Image of the Skin (Source: Microsoft Designer , Stunning Designs in a Flash, Image Generator, https://designer.microsoft.com/ 2025)	12
2	Structure of the epidermis with the different strata, resting on the dermis (Source: Shutter-shock.com, Jose Luis Calvo, News Medical 2025)	13
3	Eccrine & sebaceous glands in the dermis (Source: Mayo Foundation, 2025)	16
4	<i>Streptococcus pyogenes</i> (Source:National Institute of Allergy and Infectious Diseases (NIAID), Flickr, December 29, 2022)	19
5	Melanoma , Diseases and Conditons (Source Mayo Clinic, June 2025)	21
6	Cutaneous Malignant Melanoma dataset (Source:GDS Browser, 2025)	24
7	Selection of GSE3189 Series Data (Source:GDS Browser, 2025)	26
8	Volcano Plot I	29
9	Volcano Plot II	30
10	MA Plot	31
11	Sample Correlation Heatmap	32
12	Principal Component Analysis (PCA)	33
13	Scree Plot	33
14	Uniform Manifold Approximation and Projection	34
15	Gene Ontology Biological Processes	35
16	KEGG Pathways	36
17	ssGSEA Enrichment Scores	37
18	PCA from GSVA	38
19	ESTIMATE Scores	39
20	AliView	42
21	Consensus Tree	43
22	Sequence Logo 1	43
23	Sequence Logo 2	44
24	Sequence Logo 3	44
25	AlphaFold	45
26	M Protein expressed from emm28 gene - Pymol	46
27	M Protein expressed from emm28 gene from UniProt	46

Contents

APPROVAL OF THESIS	2
STATEMENT OF THESIS ORIGINALITY	3
Declaration of Authorship	3
Acknowledgements	4
Abstract	8
Chapter I: INTRODUCTION	9
Background & Motivation	9
Research Problem and Objectives	9
Research Questions and Hypotheses	9
Research Questions	9
Hypotheses	10
Melanoma Hypotheses:	10
S. pyogenes Hypotheses:	10
Research Significance	10
Overview of the Method	10
Structure of the Thesis	10
Chapter II: LITERATURE REVIEW	12
The Skin	12
The Function of the Skin	12
The Structure of the Skin	13
The Epidermis	13
The Dermis	15
The Hypodermis	16
Streptococcus pyogenes	18
Streptococcus pyogenes:Taxonomy, Morphology & Clinical Relevance	18
Infection of Human Skin	18
Virulence Factors of Streptococcus pyogenes	18
The M Protein	19
F proteins	20
Streptolysins and Exotoxins	20
Lipoteichoic Acid and Vaccine Targets	20
Antimicrobial Resistance	20
Biofilm Formation and Quorum Sensing in Streptococcus pyogenes	20
Melanoma	21
Introduction to Melanoma	21
Related Skin Cancers	21
Melanocyte Development and Key Pathways	22
Neuregulin-1	22
The Mitogen-Activated Protein Kinase (MAPK) signalling pathway	22
Diagnosis and Imaging Techniques	22
Molecular and Genetic Characterisation	22
Omics Approaches in Melanoma Research	23
Molecular Subtyping and Future Directions	23
Chapter III : RESEARCH METHODS	24

Overview of Research Design	24
Topic I: Melanoma — Gene Expression and Pathway Analysis	24
Topic 1: Melanoma Data and Methods	24
Data Sources	24
Data Preprocessing	24
Analytical Methods	25
Topic II: Streptococcus pyogenes — Virulence Gene & Protein Analysis	25
Data Sources	25
Data Preparation	25
Analytical Methods	25
Chapter IV: RESULTS AND ANALYSIS	26
RESULTS - Topic I: Melanoma	26
Overview of the Dataset	26
Differential Gene Expression	27
Mean-variance trend	27
Volcano Plot	29
MA Plot	31
Principal Component Analysis (PCA) & Clustering	32
Sample Correlation Heatmap	32
Principal Component Analysis (PCA)	32
Uniform Manifold Approximation and Projection (UMAP)	34
Pathway Analysis	35
Top GO Biological Processes	35
Top KEGG Pathways	36
Gene Signature Enrichment	37
Tumor Purity Estimation for Melanoma vs Nevus Samples	39
RESULTS – Topic II: Streptococcus pyogenes	40
Sequence Dataset Overview	40
Phylogenetic Analysis using PAUP	42
WebLogo	43
AlphaFold three-dimensional protein structure prediction	45
CHAPTER V : CONCLUSION	47
Appendices	49
Pymol Script to display M protein structure	49
References	51

Abstract

This thesis investigates the structural and functional aspects of the skin with a focus on two distinct but interrelated biological systems:

- 1. Cutaneous Malignant Melanoma and Nevi samples
- 2. *Streptococcus pyogenes*, a pathogenic bacterium known for skin invasiveness

The primary aim is to explore how bioinformatics approaches can be leveraged to better understand skin pathology from both oncological and microbiological perspectives.

For the melanoma analysis, high-throughput gene expression data were used to identify differentially expressed genes between melanoma and benign Nevi samples. Advanced computational methods including Linear Models for Microarray Data (LIMMA), Gene Set Variation Analysis(GSVA), and the ESTIMATE algorithm were applied to evaluate tumour purity and immune cell infiltration. Functional enrichment analyses and pathway mapping using KEGG were employed to understand the roles of key genes in tumour progression.

*In parallel, genomic data from multiple clinical strains of *Streptococcus pyogenes* were retrieved from NCBI databases to look at the diversity of specific virulence genes. Phylogenetic analyses and emm-typing were conducted to explore evolutionary patterns. Structural Bioinformatics approaches were applied to investigate the protein structure encoded by virulence genes. The overarching goal is to contribute to genomic biomarker discovery, vaccine target identification and to the broader integration of bioinformatics in dermatology and infectious disease research.*

Chapter I: INTRODUCTION

Background & Motivation

The human skin is the largest organ of the body and it serves as the first line of defence against external environmental pathogens. It is a common site for a range of diseases, from bacterial infections to malignant cancers.

In dermatological research significant attention has been directed towards understanding the onset of Melanoma. It is also important to investigate how bacterial pathogens such as *Streptococcus pyogenes* breach the skin barrier.

Melanoma remains to be one of the most aggressive forms of skin cancer. The prognosis is poor if there is a late stage diagnosis. The identification of molecular biomarkers to guide early detection of Melanoma may provide a way to deliver personalised therapies. Precision oncology, through bioinformatics may offer tools to uncover the underlying genomic architecture of melanoma and assess tumour heterogeneity patterns.

Streptococcus pyogenes is a well-documented pathogen that causes a spectrum of skin infections. The virulence of this bacterium is attributed to various factors including the M protein, encoded by the *emm* gene, which aids in immune evasion and bacterial colonisation of human host tissues. Understanding the genomic diversity and the protein structure of these virulence factors may inform vaccine development and therapeutic interventions.

This thesis aims to explore the structure and function of the skin in health and disease using bioinformatic methods, contributing new insights into two distinct domains: cancer genomics and microbial pathogenesis.

Research Problem and Objectives

The research is grounded in the application of bioinformatics methodologies to address the following central problems:

- **Melanoma Analysis:** To identify differentially expressed genes between melanoma and benign nevi, investigate tumour purity levels and map these findings onto biological pathways to elucidate cancer mechanisms.
- **Streptococcus pyogenes Analysis :** To evaluate the genetic diversity of *S. pyogenes* virulence factors, particularly the *emm* gene family, and perform structural bioinformatics analysis on proteins such as the M protein to predict their interaction with the host skin cells.

These problems are addressed through computational analyses of publicly available genomic datasets and the development of reproducible code, documented in R and hosted in a Github repository called <https://github.com/s172084/AThesis>. The research incorporates data retrieval from the NCBI, gene expression analysis using LIMMA, pathways and enrichment analysis and phylogenetic tree construction.

Research Questions and Hypotheses

Research Questions

- 1. Which key genes are differentially expressed between melanoma and nevi, and how do they contribute to tumour development and immune response?
- 2. What is the genetic diversity of virulence factors, particularly the *emm* genes, across different *S. pyogenes* strains, and how does this correlate with infection severity?
- 3. Can structural bioinformatics reveal conserved residues in virulence proteins that serve as potential therapeutic targets?

Hypotheses

Melanoma Hypotheses:

- Certain genes are significantly upregulated or downregulated in melanoma compared to nevi, and these genes are enriched in immune system-related GO terms and pathways.
- Tumour samples exhibit variable immune infiltration and stromal content, which can be quantified using the ESTIMATE algorithm.
- Network analysis will reveal key genes and protein interactions involved in melanoma pathogenesis.

S. pyogenes Hypotheses:

- *S. pyogenes* strains share a conserved set of core virulence genes, with strain-specific variants contributing to clinical outcomes.
- Phylogenetic clustering of strains aligns with emm types and their associated virulence profiles.
- The M protein contains conserved structural motifs essential for binding to human skin receptors.
- Structural variants in virulence proteins correlate with host immune evasion strategies and tissue tropism.

Research Significance

The integration of genomics, bioinformatics, and structural biology in this research holds practical relevance for both oncology and infectious diseases. By identifying biomarkers and understanding the molecular interactions of pathogens and tumors with skin tissue, this research may:

- Support the development of targeted therapies and vaccines.
- Advance precision medicine approaches tailored to individual genetic profiles.
- Enhance interdisciplinary collaboration between computational biology and clinical research.

Overview of the Method

The research employs a multi-faceted computational pipeline:

Melanoma Analysis: Differential gene expression (LIMMA), GSVA/ssGSEA, KEGG pathway analysis, ESTIMATE scoring.

***S. pyogenes* Analysis:** Genomic sequence download from NCBI, emm typing, phylogenetic tree construction, protein structure prediction.

All code is written in R and stored in a public GitHub repository alongside the data and visualisations. The thesis document is written in RMarkdown and compiled to PDF, with reference management facilitated by Zotero.

Structure of the Thesis

This thesis is submitted in fulfilment of the requirements for a master's degree in bioinformatics and serves as a demonstration of advanced research competences. It aims to exhibit the ability to define a clear research question, conduct a comprehensive review of the literature and apply appropriate research methodologies.

The objective of this study is to critically evaluate existing academic work and to contribute new insights or perspectives that may advance scholarly understanding or have practical relevance.

The thesis presents my only opportunity to dive deeply into specific topics related to the structure and function of the skin, Cutaneous Malignant Melanoma and ***Streptococcus pyogenes*** bacteria.

The research is part of a bigger github portfolio which contains all code and images and this thesis which has been written during the Spring Season of 2025.

The references are made using Zotero² and are listed in the references.bib file which was used to make the references below in the rmarkdown document. The thesis is written in RMarkdown and knitted to pdf.

Chapter II: LITERATURE REVIEW

The Skin

The Function of the Skin

The skin is the largest organ of the human body and is comprised of a diverse array of specialised cell types. It serves as a critical barrier that protects the internal organs from bacteria invasion, environmental pathogens, ultraviolet (UV) radiation and various biochemical agents. In addition to its protective role, the skin plays a fundamental part in thermoregulation by modulating body temperature and enabling adaptation to fluctuating environmental conditions.³

Furthermore, the skin facilitates the excretion of sweat, sebum, and metabolic waste products through its glandular structures³. It possesses wound-healing capabilities, allowing for the repair of abrasions, lacerations and other forms of tissue injury³. The subcutaneous fat layer functions as a mechanical cushion, providing shock absorption and an additional line of defence against infection³.

The skin also contributes to endocrine function through its role in the synthesis of vitamin D upon exposure to UV radiation³. Additionally, it plays a vital sensory role, continuously transmitting information to the central nervous system regarding the external environment⁴. The skin is integrated with the nervous system to enable the perception of thermal stimuli, tactile sensations, and other sensory inputs essential for survival and interaction with the environment³.

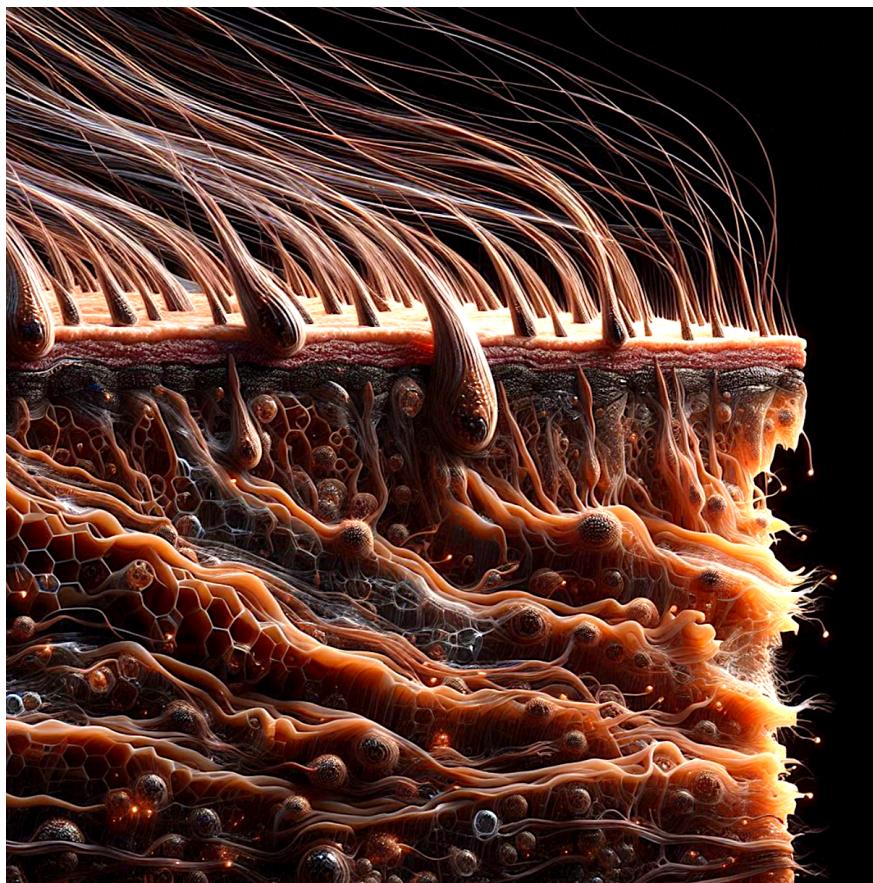


Figure 1: AI Image of the Skin (Source: Microsoft Designer , Stunning Designs in a Flash, Image Generator, <https://designer.microsoft.com/> 2025)

Image created by Microsoft Designer⁵.

The Structure of the Skin

The skin is composed of three primary layers: the **epidermis**, the **dermis**, and the **hypodermis** (also known as the subcutaneous fat layer). Each layer performs specific functions essential to maintaining homeostasis, immunity and overall health.

The Epidermis

The **epidermis** is the outermost layer of the skin and is primarily composed of keratinocytes, which are specialised cells responsible for the synthesis of keratin, cytokines, growth factors and interleukins. This layer provides the first line of defence against environmental pathogens and is organised into four distinct strata, arranged from superficial to deep.

- *The Stratum corneum*
- *The Stratum granulosum*
- *The Stratum spinosum*
- *The Stratum basale* (also referred to as the *stratum germinativum* or the basal cell layer).

An illustrative representation of the epidermis is provided below⁶.

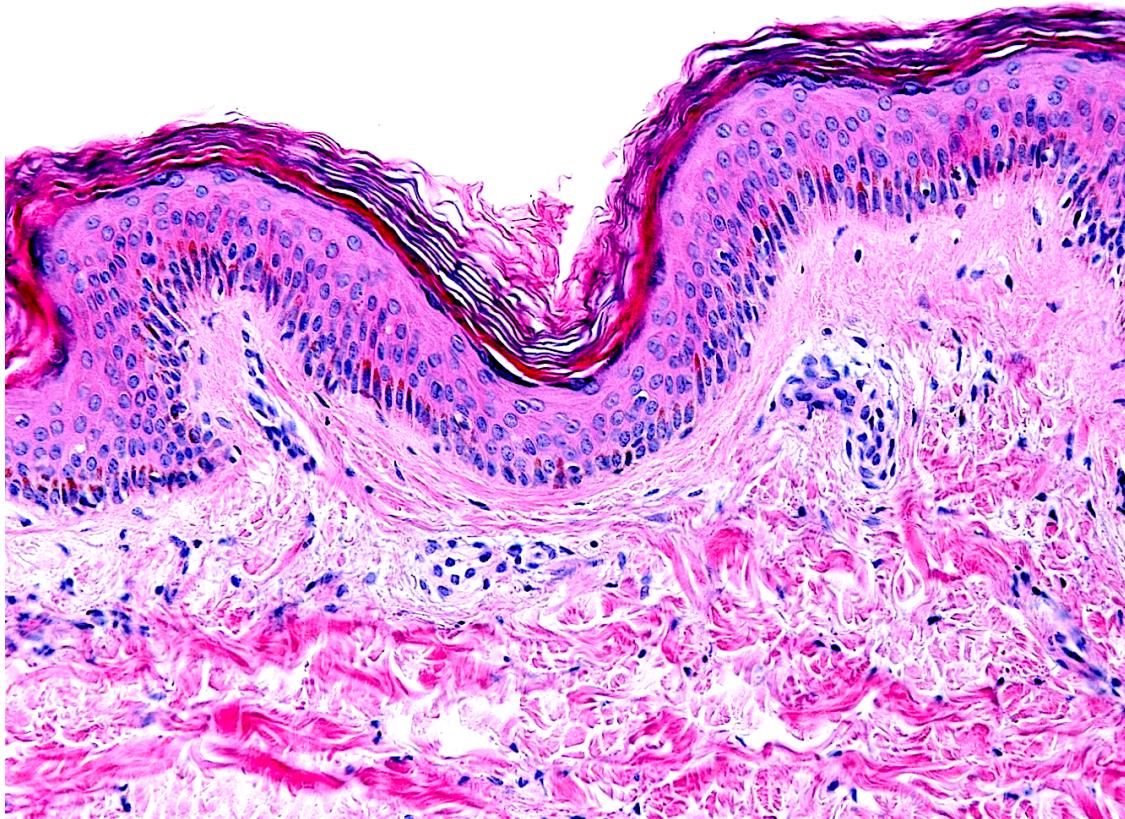


Figure 2: Structure of the epidermis with the different strata, resting on the dermis (Source: Shutterstock.com, Jose Luis Calvo, News Medical 2025)

The **stratum corneum** consists of *terminally differentiated* keratinocytes. Terminally differentiated cells exit the cell cycle as they can no longer divide. The keratinocytes become corneocytes in the stratum corneum. Corneocytes are non-viable, enucleated cells⁷.

The corneocytes function to minimise transepidermal water loss and provide protection against mechanical and microbial damage. Keratin produced in the underlying layers accumulates in the corneocytes, which are eventually shed through a natural process known as desquamation.

The skin surface is interspersed with pores, which serve as conduits for the excretion of sweat and sebum via eccrine and sebaceous glands, respectively⁴.

The **stratum spinosum**, or *prickle cell layer*, lies above the stratum basale and consists of keratinocytes connected by desmosomes, which provide structural support. In this layer, keratinocytes begin producing cytokeratins that form tonofibrils. Langerhans cells, involved in immune defence, are also present in this layer.

The **stratum granulosum** contains flattened keratinocytes that undergo terminal differentiation. Keratinocytes accumulate keratohyalin granules, involved in keratin aggregation, and lamellar bodies, which secrete lipids that form a barrier to water loss. Keratinocytes in this layer begin to lose their nuclei and organelles as they prepare for transformation into dead corneocytes of the uppermost layer ;the stratum corneum.

The **stratum basale** (or stratum germinativum) is the deepest layer of the epidermis and plays a central role in skin regeneration. This layer has mitotically active keratinocytes, which divide to replenish the upper layers. In addition to keratinocytes, several other specialised cells are found within this layer :

- **Melanocytes**, which produce melanin, the pigment responsible for skin colour and protection against ultraviolet (UV) radiation⁸.
- **Langerhans Cells**, (LCs) a type of dendritic cell (DC) that originate from hematopoietic stem cells in the bone marrow. They have a role in immune surveillance by recognising antigens and initiating T-cell responses⁷.
- **Merkel cells**, which are mechanoreceptors involved in the sensation of touch.
- **Dendritic cells**, which also play a defence role in the immune response as they differentiate into macrophages⁷.

Within the **stratum basale** UV radiation stimulates the conversion of provitamin D₃ into pre-vitamin D₃ that initiates the cutaneous synthesis of vitamin D. Subsequent hydroxylation in the liver and kidneys leads to the production of the active form of vitamin D⁷.

The epidermis is not only a structural barrier but also a site of pathological relevance. Several dermatological and systemic conditions occur in this layer including **seborrhoeic dermatitis** (dandruff), **psoriasis**, **atopic dermatitis** (eczema), melanoma, **acne vulgaris** , **actinic keratoses** and pressure ulcers (decubitus ulcers)⁴.

The Dermis

The dermis is the middle layer of the skin, situated beneath the epidermis, and serves as the primary site of structural and functional support. It contains many essential components including blood vessels such as capillaries⁷, lymphatic vessels, sweat glands, sebaceous glands, hair follicles, nerve endings, and specialised sensory receptors. The dermis is primarily composed of **collagen** and **elastin**, two fibrous proteins that confer tensile strength and elasticity, respectively.

The dermis is subdivided into two distinct layers:

- **The papillary dermis**, the superficial layer, which is composed of loose connective tissue and contains capillaries and sensory neurons.
- **The reticular dermis**, the deeper layer, composed of dense irregular connective tissue rich in collagen and elastin fibres, glands, hair follicles, and larger blood vessels.

The dermis contains sweat glands, sebaceous glands, blood vessels, lymphatic vessels, and other structures critical to skin function. These glands play essential roles in thermoregulation, lubrication, and excretion. The eccrine glands are responsible for sweat production, while the sebaceous glands secrete sebum to maintain skin hydration and barrier function. Both are embedded within the dermal layer and are regulated by hormonal and neural signals.

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Fibroblasts, the predominant cell type in the dermis, are responsible for synthesising collagen proteins, and other components of the extracellular matrix, which maintains the structural framework of connective tissues. In addition to their structural role, fibroblasts are actively involved in **wound healing** through production of signalling molecules and matrix proteins⁹.

Collagen is the most abundant protein in the human body and is found not only in the skin but also in muscles, bones, tendons, ligaments, blood vessels, internal organs and the gastrointestinal lining¹⁰. The primary amino acids in collagen include glycine, proline and hydroxyproline, which assemble into a characteristic triple-helix structure to form collagen fibrils. The biosynthesis of this structure requires several cofactors, including **vitamin C, zinc, copper and manganese**¹⁰.

Among the specialised mechanoreceptors in the dermis are Meissner's corpuscles and Pacinian corpuscles, which detect mechanical stimuli such as touch, pressure, and vibration. These corpuscles are multicellular structures (of multiple cell types) consisting of a sensory nerve ending surrounded by specialised Schwann cells.

The vascular network within the dermis plays a crucial role in thermoregulation by adjusting blood flow in response to temperature changes⁷. The nerve endings transmit sensory information such as touch, pain, and temperature⁷. Dermal immune cells contribute to the inflammatory response following injury or infection.

The dermis contains a diverse population of cells, including fibroblasts, immune dendritic cells, macrophages, T lymphocytes, mast cells, innate lymphoid cells, neutrophils, eosinophils, and natural killer cells, neuronal cells and endothelial cells¹¹.

Among the immune cells, T lymphocytes are predominantly located in close proximity to blood vessels, vessels, hair follicles and sweat glands within the dermis. Subsets of T cells perform distinct immunological functions: **Th1 cells** secrete cytokines that enhance the capacity of other immune cells to target and eliminate pathogens; however, dysregulation of Th1 activity may contribute to the development of autoimmune disorders¹¹. **Th2 cells** are primarily involved in the mediation of allergic responses. **Th17 cells** play a crucial role in defending against bacterial and fungal infections and are implicated in the pathogenesis of inflammatory skin diseases such as eczema and psoriasis.

In contrast, **regulatory T cells (Tregs)** modulate immune responses by suppressing excessive inflammation through the release of inhibitory signals and by eliminating over-active immune cells, thereby maintaining immune homeostasis with the dermis¹¹.

Several conditions originate within the dermis, including wrinkles (due to collagen degradation), cellulitis (a bacterial skin infection), dermoid cysts (which may contain hair or teeth), sebaceous cysts, and dermatofibromas.

An illustrative representation of the dermis containing sweat glands, sebaceous glands, blood vessels, lymphatic vessels is shown below¹².

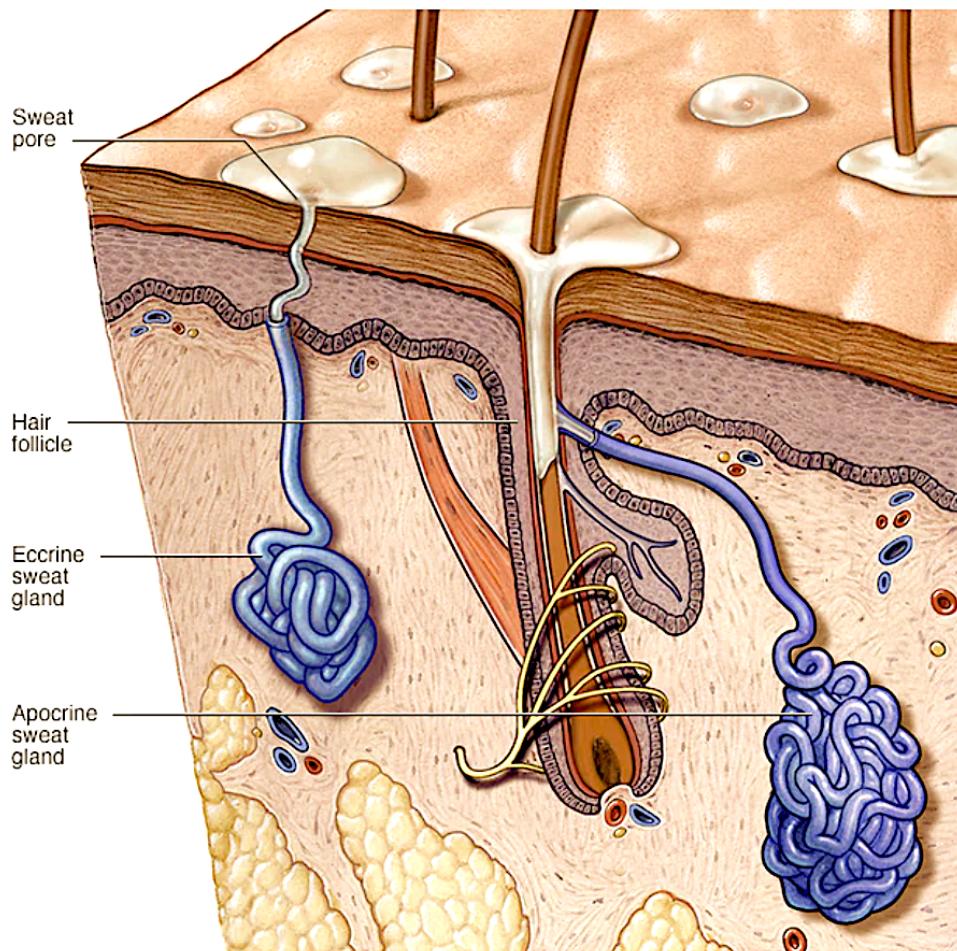


Figure 3: Eccrine & sebaceous glands in the dermis (Source: Mayo Foundation, 2025)

The Hypodermis

The **hypodermis**, also known as the subcutaneous layer of fat, lies beneath the dermis and primarily consists of adipose tissue. This layer is composed of lipocytes that function to insulate the body, maintain thermoregulation, and serve as an energy reserve. The hypodermis also plays a crucial role in absorbing mechanical shock and protecting underlying muscles and organs.

Structurally, the hypodermis includes the following key components:

- Fibroblasts: Cells responsible for the production of collagen¹³. They also regulate the immune response to producing cytokines and chemokines¹¹.

- Adipose tissue: Specialised are fatty tissues composed of lipocytes¹³
- Connective tissue: A network of collagen and elastin fibres that support and anchors, and gives structure to other tissues¹³.
- Blood vessels: Including arteries, veins and capillaries that supply the skin with oxygen rich blood and nutrients, while facilitating thermoregulation¹³.
- Lymphatic vessels: Structures involved in maintaining fluid homeostasis and transporting lymph, a fluid containing immune cells and waste products¹³.
- Hair follicles: Structures that anchor individual hair shafts and are associated with sebaceous glands and nerve endings.
- Nerve fibres: Sensory neurons the body's sense of position and movement in space.

The hypodermis functions as a supportive and protective layer and has important vascular, immune and sensory roles.

Streptococcus pyogenes

Streptococcus pyogenes: Taxonomy, Morphology & Clinical Relevance

Streptococcus pyogenes is a Gram-positive, anaerobic bacterium commonly referred to as Group A Streptococcus (GAS)¹⁵.

The Gram-positive nature is due to a thick peptidoglycan layer in its cell wall, which retains the crystal violet stain.

Structurally, *S.pyogenes* is characterised by its beta-hemolytic activity, meaning it causes complete lysis of red blood cells on blood agar plates. Morphologically, the cells are small, spherical, and typically arranged in chains, a feature that distinguishes them from other bacterial species¹⁵.

Taxonómically, *S.pyogenes* is classified as follows:

- **Domain:** *Bacteria*
- **Kingdom:** *Bacillati*
- **Phylum:** *Bacillota*
- **Class:** *Bacilli*
- **Order:** *Lactobacillales*
- **Family:** *Streptococcaceae*
- **Genus:** *Streptococcus*
- **Species:** *S.pyogenes*¹⁵

As a highly adaptable pathogen, *S.pyogenes* is capable of causing a wide range of clinical diseases, from mild superficial infections to severe invasive conditions. Its chain-like cellular arrangement and distinct beta-hemolytic properties are key identifiers in both clinical and microbiological contexts.

Infection of Human Skin

Streptococcus pyogenes is a significant pathogen responsible for a wide spectrum of clinical diseases. Prompt diagnosis and treatment of *S.pyogenes* infections are critical due to the organism's capacity to cause both superficial and systemic illnesses.

Skin infections caused by *S.pyogenes* range from localised conditions such as impetigo to more severe and invasive diseases, including necrotising fasciitis, a life-threatening infection of the deep dermal and subcutaneous tissues¹⁵.

In addition to skin infections, *S.pyogenes* is known to cause pharyngitis, pneumonia, scarlet fever, acute post-streptococcal glomerulonephritis, and the autoimmune condition rheumatic fever. In chronic cases, *S.pyogenes* may also contribute to the development of rheumatic heart disease.

Virulence Factors of Streptococcus pyogenes

Virulence factors are molecules produced by pathogens that facilitate infection, survival and damage within the host. *S.pyogenes* expresses a diverse array of virulence factors that enable its pathogenicity, immune system invasion, and tissue invasion¹⁵.

1. **Capsules** The bacterium produces a capsule that protects it from being engulfed by the host immune cells.
2. **Adherence Factors** Adherence factors (Adhesins), including lipoteichoic acid (LTA) and fibronectin-binding proteins help the bacterium to attach to host epithelial cells and tissues.

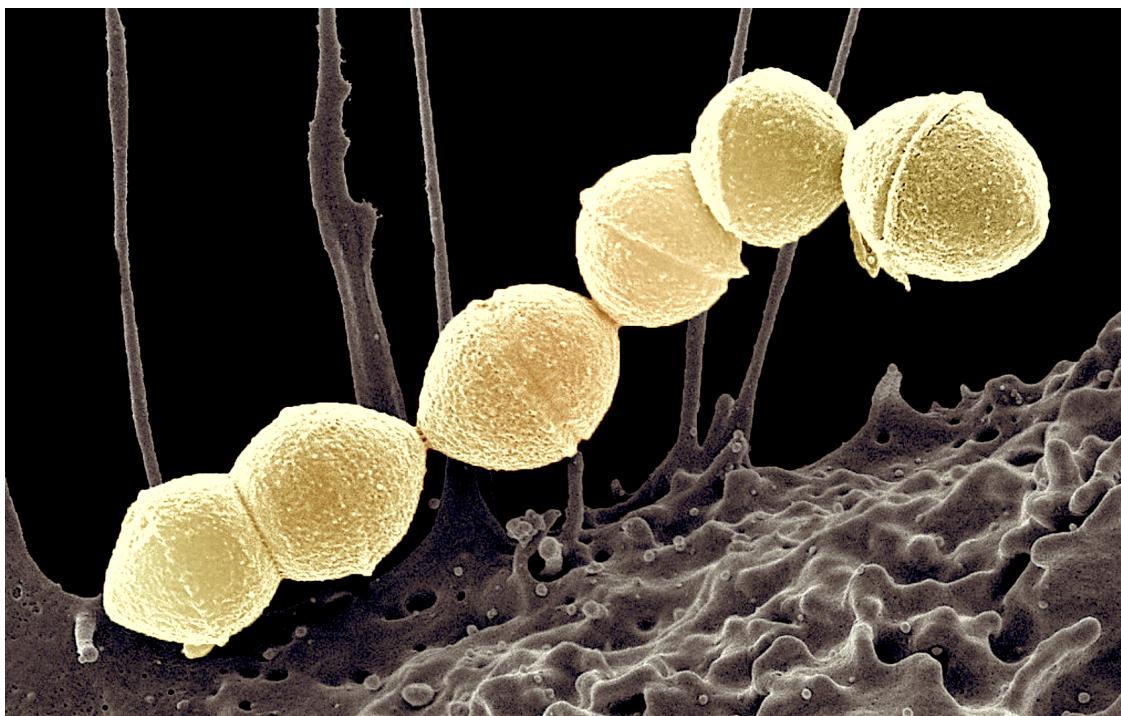


Figure 4: *Streptococcus pyogenes* (Source:National Institute of Allergy and Infectious Diseases (NIAID), Flickr, December 29, 2022)

3. Surface Proteins Surface proteins such as M protein and related members (e.g. Mrp and Enn) play crucial roles in immune evasion. These proteins have variable antigens which allow the pathogen to avoid recognition by the host immune system.

4. Enzymes *S.pyogenes* secretes several enzymes that degrade host tissues and promote bacterial invasion. These include:

- **Streptokinase:** Converts plasminogen to plasmin, aiding in the breakdown of fibrin blood clots.
- **Hyaluronidase:** Degrades hyaluronic acid in connective tissue, facilitating bacterial spread.
- **DNases:** Break down extracellular DNA.

5. Toxins *S.pyogenes* produces streptolysins (SLO and SLS), exotoxins that lyse red blood cells and other host cells. Additionally, streptococcal pyrogenic exotoxins (SPEs) are super-antigens that activate T cells and induce a massive immune response. At least three distinct SPEs have been identified¹⁵.

The M Protein

The M protein is a major virulence factor encoded by the emm gene family, which is present in all *S.pyogenes* strains¹⁴. These surface-anchored proteins are involved in adherence, immune evasion, and resistance to phagocytosis.

The M protein is considered one of the most important virulence factors.

- **Structure:** The M protein is a coiled-coil molecule anchored in the bacterial membrane, with a highly variable N-terminal region responsible for antigenic diversity.
- **Function:** It interferes with opsonisation and complement activation, making it a key player in immune system evasion. The M-protein changes surface antigens to make it harder for the host to recognise the pathogen.

- **Variants:** M-related proteins such as Mrp and Enn, along with fibronectin-binding proteins, are also expressed and contribute to pathogenicity.

F proteins

F proteins are another group of surface adhesins produced by *S.pyogenes*. These include fibrinogen-binding and fibronectin-binding proteins, which facilitate tight adherence to host tissues and are critical in the early stages of infection.

Streptolysins and Exotoxins

- Streptolysin O (SLO) and Streptolysin S (SLS) are cytolytic toxins that cause hemolysis and contribute to tissue damage during infection.
- Streptococcal pyrogenic exotoxins (SPEs) are potent super-antigens activate T cells and stimulate a massive immune response, often leading to severe systemic symptoms.

Lipoteichoic Acid and Vaccine Targets

Lipoteichoic acid is a key surface molecule involved in adherence and immune activation, and it is under investigation as a potential target for vaccine development¹⁵.

Antimicrobial Resistance

S.pyogenes also harbours genes associated with antimicrobial resistance. Notable among these are:

- **lmrP:** Encodes a multidrug efflux pump
- **tetM and tetL:** Confer resistance to tetracyclines.
- **tgfT:** involved in resistance to specific antimicrobial agents¹⁷.

These resistance genes highlight the need for continuous surveillance and prudent use of antibiotics in treating *S.pyogenes* infections.

Biofilm Formation and Quorum Sensing in *Streptococcus pyogenes*

Biofilms are structured microbial communities encased within a self-produced extracellular matrix. In *Streptococcus pyogenes*, biofilm formation facilitates communication between cells and contributes to bacterial survival, particularly under host immune response and exposure to antibiotics. This communication is mediated by a mechanism known as quorum sensing, which regulates gene expression in response to cell density.

In *S.pyogenes*, one of the key quorum sensing pathways involved in biofilm development is the Rgg2/3 pathway. This pathway controls the expression of genes involved in biofilm formation through the modulation of short hydrophobic peptides, which act as quorum sensing pheromones, also referred to as autoinducers.

Short hydrophobic peptides are initially synthesised in an immature form within the bacterial cell. To become functionally active, these peptides undergo a two-step processing mechanism. First, an intracellular metalloprotease enzyme processes the SHPS. Subsequently, they undergo further processing in the extracellular environment to reach their mature, biologically active form.

The specific transport mechanism responsible for the SHP export and the identity of the extracellular processing factor(s) remain to be elucidated.

The Rgg2/3 pathway is essential for biofilm maturation and plays a central role in *S.pyogenes* pathogenesis, particularly in facilitating persistent infections by enhancing resistance to host immune defences and antimicrobial agents.

Melanoma

Introduction to Melanoma

Melanoma is a highly prevalent form of skin cancer originating from the melanocytes²¹.

As mentioned in the earlier section, Melanocytes are cells that contribute to skin colouration due to the creation of melanin²². A tumour occurs when the DNA mutates inside of the Melanocyte cells²³. Melanoma is notable for its high metastatic potential²⁴.

Melanoma has several distinct subtypes, including Acral Melanoma²⁵, Mucosal Melanoma and Uveal Melanoma, each arising in different anatomical sites and with unique molecular profiles²³. In contrast to keratinocyte carcinomas which include basal cell carcinoma and squamous cell carcinoma, these melanomas originate from melanocytes²⁵.

Related Skin Cancers

Other rare cutaneous malignancies include Sebaceous Carcinoma and Apocrine Adenocarcinoma, as well as Merkel Cell Carcinoma, a neuroendocrine tumour strongly linked with exposure to ultraviolet light. Although these cancers are less common than melanoma, they use similar methods for diagnosis and molecular testing.

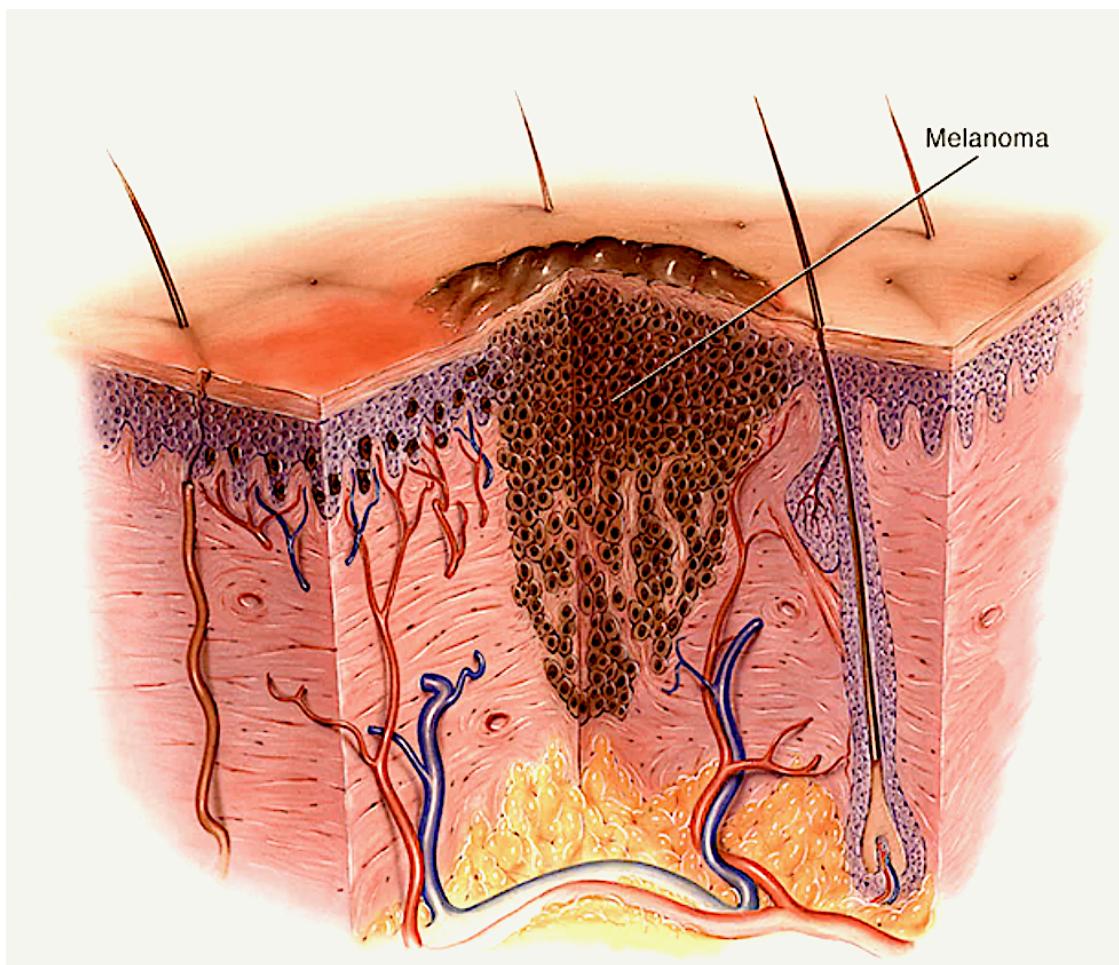


Figure 5: Melanoma , Diseases and Conditons (Source Mayo Clinic, June 2025)

Melanocyte Development and Key Pathways

The development of Melanocytes from neural crest cells (NCCs) is regulated by a network of growth factors and intracellular signalling pathways⁸.

The most important regulatory molecules are endothelins and stem cell factors. Stem cell factors are ligands for the c-Kit receptor. Other critical growth factors include members of the Wnt protein family and Neuregulin-1 (NRG1).

Neuregulin-1

Neuregulin-1 (NRG1) is a growth factor that is known for its pleiotropic effects¹⁸. In addition to its role in melanocyte biology, NRG1 is a key growth factor within the nervous system. It promotes development of Schwann cells, glial cells that form the myelin sheath, while also supporting neuron growth and enhancing synaptic plasticity.

Furthermore, Neuregulin-1 contributes to the repair of the cardiac and vascular tissues and acts via ErbB receptors.

The Mitogen-Activated Protein Kinase (MAPK) signalling pathway

The Mitogen-Activated Protein Kinase (MAPK) signalling pathway is central to the development of melanocytes²¹. This pathway plays a fundamental role in cell survival, proliferation and differentiation. Signalling pathways are cascades of protein interactions that respond to growth factors to direct the cells.

The MAPK pathway is activated when stem cell factors bind to the c-Kit receptors on the melanoblast cell surface. The binding event initiates a signalling cascade that leads to the activation of extracellular signal-regulated kinases (ERKs). These kinases move into the nucleus and activate gene expression processes required for melanocyte development and melanin biosynthesis.

Understanding how melanocytes normally develop is important for figuring out how melanoma begins and spreads, since problems in these signalling pathways are often involved in the disease process.

Diagnosis and Imaging Techniques

Magnetic Resonance Imaging (MRI) is the primary diagnostic tool for Melanoma. MRI can be conducted with or without the use of contrast agents to enhance lesion visualisation. In cases where imaging results are inconclusive or suspicious, a biopsy is performed to obtain a tissue sample for histological and molecular examination¹⁹.

Histopathological analysis typically involves immunohistochemical staining protocols, where tissue samples are incubated in biotin and stained using haematoxylin blue/black nuclear stain and eosin pink cytoplasmic stain to highlight cellular architecture and pathology¹⁹. To preserve biological integrity for subsequent analyses, the specimen are often cryopreserved.

Molecular and Genetic Characterisation

The identification of genetic mutations and molecular pathways involved in melanoma is pivotal for both diagnosis and the development of targeted therapies. Several genes are recognised as therapeutic biomarkers and are investigated for the presence of mutations¹⁹.

Minimal Residual Disease (MRD) relates to the small number of cancer cells that may remain in the body during or after treatment for Melanoma and potentially lead to recurrence. Minimal Residual Disease is typically assessed via liquid biopsy, a minimally invasive technique that analyses circulating tumour DNA (ctDNA) in cerebrospinal fluid, blood or urine.

This ctDNA analysis is referred to as fragmentomics and it uses advanced techniques such as Digital PCR (dPCR) and Droplet Digital PCR (ddPCR) to detect mutations.

Micro-RNAs (microRNA) also play a significant role in melanoma pathogenesis. For example, miR-21 is often up-regulated in patients with Melanoma and breast cancer. These non-coding RNAs are regulators of gene expression and may serve as diagnostic and prognostic biomarkers¹⁹.

Omics Approaches in Melanoma Research

Comprehensive molecular profiling using omics based technologies has changed the classification and understanding of melanoma¹⁸. Transcriptomics, which investigates the full range of RNA transcripts expressed in tumour cells, provides insight into the functional state of cancerous tissues¹⁸. Methylomics, focusing on DNA methylation patterns reveals epigenetic modifications that contribute to the oncogenesis and may serve as early diagnostic indicators. Microarray based transcription profiling is employed for high throughput analysis of gene expression, while cell surface proteomic analysis enables the identification of differentially expressed membrane proteins.

Molecular Subtyping and Future Directions

Molecular subtyping of melanoma has become a cornerstone of personalised oncology. By integrating data from genomics, transcriptomics and proteomics, clinicians and researchers can classify tumours into subtypes that inform prognosis and therapeutic response. This systems biology approach not only enhances diagnostic precision but also opens up avenues for novel targeted treatments²⁶. Bioinformatics studies may provide a clearer understanding of the molecular mechanisms behind melanoma metastasis²⁶.

Further insights into the overlap between cutaneous and Uveal Melanoma have been gained through bioinformatics approaches which identify shared gene expression signature and signalling pathways²³. Such comparative analyses deepen the understanding of melanoma heterogeneity and path the way for cross-subtype therapeutic strategies²⁶.

Chapter III : RESEARCH METHODS

Overview of Research Design

This thesis investigates two biologically distinct but methodologically complementary topics:

- The analysis of gene expression and immune-related pathways in melanoma
- The genomic and structural analysis of virulence genes in *Streptococcus pyogenes*.

Despite being different biological systems, both studies rely on bioinformatics and integrative genomic approaches.

Topic I: Melanoma --- Gene Expression and Pathway Analysis

Topic 1: Melanoma Data and Methods

Data Sources

- National Centre for Biotechnology Information (NCBI) Gene Expression Omnibus (GEO) dataset

The data used in this study were obtained from publicly available databases and include the *Cutaneous Malignant Melanoma* dataset. Specifically, I utilized gene expression data and associated clinical information from tumour samples available through the National Centre for Biotechnology Information (NCBI) Gene Expression Omnibus (GEO).

- Clinical information, GPL96 Affymetrix Microarray Data, gene expression

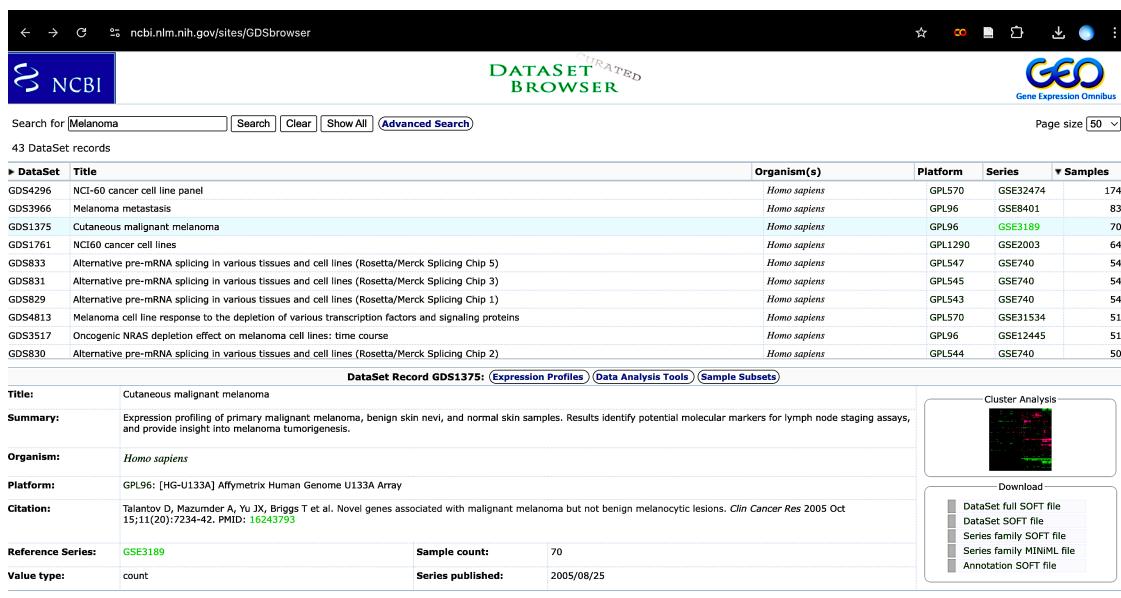


Figure 6: Cutaneous Malignant Melanoma dataset (Source:GDS Browser, 2025)

Data Preprocessing

Normalization, filtering, preprocessing tools

Analytical Methods

- Linear Models for Microarray and Omics Data (LIMMA) : Differential Gene Expression
 - Principal Component Analysis
 - KEGG/Pathway analysis
 - GSVA / ssGSEA
 - Tumour Analysis using the ESTIMATE package
-

Topic II: Streptococcus pyogenes --- Virulence Gene & Protein Analysis

Data Sources

- Public databases (National Center for Biotechnology Information (NCBI) , AlphaFold)
- Genomic Data Acquisition (FASTA files)
- Download of genomic and protein sequence data of multiple *S. pyogenes* strains from NCBI.
- Standardized file naming and merging into emm.fasta.
- Include Table of emm genes and strains.

The genomic sequence data for this study was obtained from the National Centre for Biotechnology Information (NCBI) GenBank database. The complete coding sequences of several emm genes encoding the M protein from *Streptococcus pyogenes* of various strains were downloaded. These DNA sequences were originally submitted to GenBank by Murayama et al. from the Laboratory of Molecular Cell Biology, School of Pharmacy, Nihon University, Japan and subsequently published in the database.

These sequences represent a linear bacterial DNA fragment. Each fragment contains the complete coding sequence for the M protein, a major virulence factor of *Streptococcus pyogenes*²⁷.

Data Preparation

- Renaming FASTA files
- Merging into emm.fasta (unix commands)

Analytical Methods

- MUSCLE alignment of emm genes
- WebLogo Motif Analysis
- Phylogenetic Tree Construction
- Use aligned sequences to infer phylogeny and strain relationships.
- Evaluate whether emm-type clusters correlate with virulence gene presence.
- Protein Structure Prediction
 - Use Swiss-Model and PyMOL to model M protein structure

Chapter IV: RESULTS AND ANALYSIS

RESULTS - Topic I: Melanoma

Overview of the Dataset

The dataset selected for this study is the *Cutaneous Malignant Melanoma* dataset, identified by GEO Data Set (GDS) accession number **GDS1375** and series number **GSE3189**, comprised of a total of 70 samples. This dataset was made publicly available on the 25th day of August in 2005. It consists of microarray gene expression profiles from three distinct sample groups: 45 malignant melanoma samples, 18 benign skin nevus samples and 7 normal skin samples.

For the purposes of this analysis, the SOFT file was downloaded and both the phenotype data and gene expression counts were extracted and processed. From the full dataset, a subset was selected for differential analysis, comprising of 21 malignant melanoma samples and 14 skin nevus samples. The 7 normal skin samples were excluded from this comparative analysis.

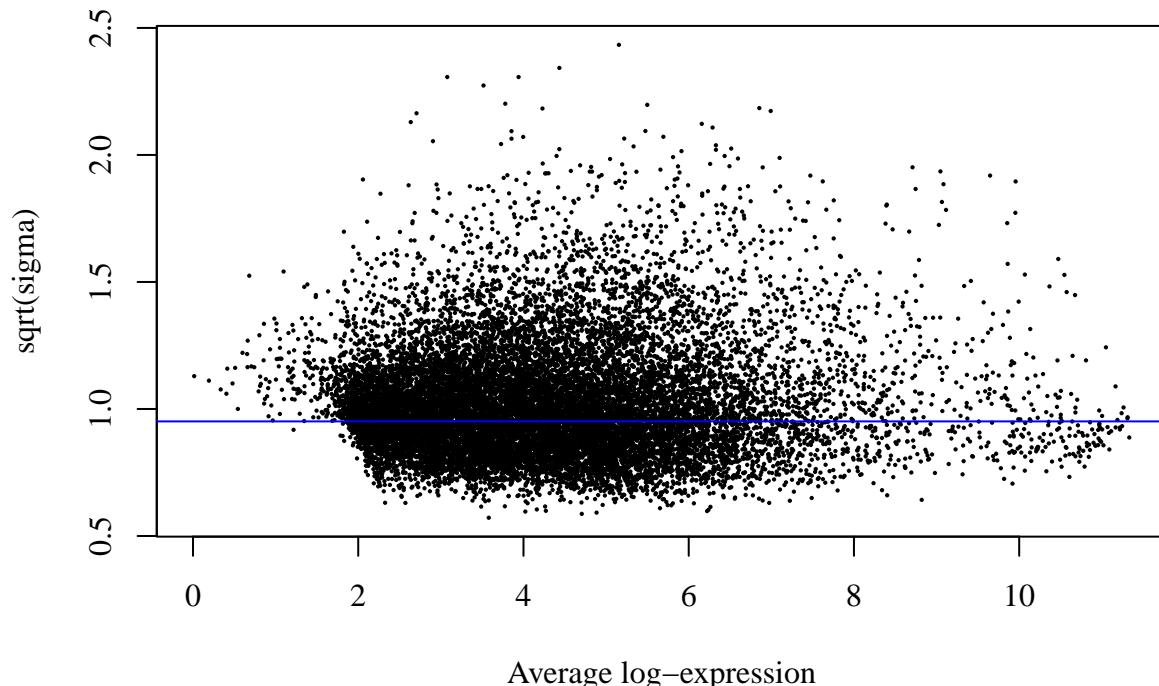
The screenshot shows the NCBI GEO Accession Display page for Series GSE3189. At the top, there are search and navigation links for GEO Publications, FAQ, MIAME, Email GEO, and Login. The main content area displays detailed information about the dataset, including its status (Public on Aug 25, 2005), title (Novel genes associated with malignant melanoma but not benign melanocytic lesions), organism (Homo sapiens), experiment type (Expression profiling by array), and summary (A number of melanoma specific genes were identified to differentiate clinical relevant tissue samples containing benign from malignant melanocytes). It also lists the overall design (7 normal skin, 18 nevi and 45 melanoma samples) and a citation (Talantov D, Mazumder A, Yu JX, Briggs T et al. Novel genes associated with malignant melanoma but not benign melanocytic lesions. *Clin Cancer Res* 2005 Oct 15;11(20):7234-42. PMID: 16243793). Below this, there is a section for "Analyze with GEO2R" which includes contact information for Tim Jatkoe (Email: tjakoe@vxrux.jnj.com, Phone: (858) 320-3315, Organization: Veridex) and their address (Street address: 1000 University City Science Center, City: San Diego, State/province: CA, ZIP/Postal code: 92121, Country: USA). The platforms used are GPL96 [HG-U133A] Affymetrix Human Genome U133A Array and GSM71671 - 430MM. There are also links for "More..." and "Samples (70)".

Figure 7: Selection of GSE3189 Series Data (Source:GDS Browser, 2025)

Differential Gene Expression

Mean-variance trend

Mean variance trend, GSE3189



This is a diagnostic plot where each point represents a gene. The x-axis shows the average log2-counts per million (logCPM) for each gene. The y-axis shows the estimated variance (or square root of standard deviation) of the log2 expression values for each gene. The trend line is plotted over the points to estimate the mean-variance relationship in the dataset. The mean-variance trend shows a relatively stable variance across expression levels, indicating the normalization and statistical modelling are appropriate for differential expression analysis.

Table 1: (Table of Top 20 Significantly Up-regulated Genes)

Gene Symbol	Log FC	Ave Expr	P-Value	Adj P-Value
NTRK3	5.574	5.693	0.0000129	0.0001071
WFDC1	5.222	4.888	0.0000264	0.0001952
HEY1	5.047	4.436	0.0000000	0.0000000
GDF15	4.964	5.666	0.0000000	0.0000000
NTRK3	4.946	5.498	0.0001644	0.0009026
PHACTR1	4.654	4.232	0.0000001	0.0000024
NTRK3	4.639	5.913	0.0000029	0.0000314
SPP1	4.363	5.332	0.0000000	0.0000004
ABHD2	4.228	4.999	0.0000002	0.0000035
NTRK3	3.960	6.619	0.0000000	0.0000011
KIF23	3.849	2.064	0.0001005	0.0005954
MIR6872 /// SEMA3B	3.819	3.665	0.0000005	0.0000077
RNFT2	3.800	1.402	0.0000763	0.0004709
NTRK3	3.792	6.718	0.0000001	0.0000016
RASGRF1	3.698	1.962	0.0044561	0.0144427
NTRK3	3.668	6.624	0.0000001	0.0000014
UBE2S	3.557	5.534	0.0000000	0.0000003
ATP6V0E2	3.540	6.915	0.0000000	0.0000000
BCL2A1	3.531	4.655	0.0000000	0.0000000
ARHGAP8 /// PRR5-ARHGAP8	3.522	2.658	0.0147619	0.0385832

Table 2: (Table of Top 20 Significantly Down-regulated Genes)

Gene Symbol	Log FC	Ave Expr	P-Value	Adj P-Value
KRT15	-8.013	3.912	0.0000000	0.0000000
KRT14	-7.298	6.514	0.0000000	0.0000000
LOR	-6.931	5.048	0.0000000	0.0000000
LGALS7 /// LGALS7B	-6.740	5.159	0.0000000	0.0000000
KRT1	-6.686	6.289	0.0000000	0.0000000
SERPINB5	-6.510	3.593	0.0000000	0.0000000
PKP1	-6.493	3.489	0.0000002	0.0000028
KRT5	-6.399	6.329	0.0000000	0.0000000
LY6D	-6.246	3.688	0.0000000	0.0000000
S100A7	-6.224	4.062	0.0000008	0.0000109
FGFR3	-6.213	3.892	0.0000002	0.0000035
HOPX	-6.075	4.480	0.0000000	0.0000000
AQP3	-5.998	5.094	0.0000000	0.0000000
SFN	-5.965	3.973	0.0000000	0.0000010
TACSTD2	-5.873	5.161	0.0000000	0.0000000
PPL	-5.805	3.711	0.0000000	0.0000000
SPRR1A	-5.713	2.635	0.0031335	0.0107551
CHL1	-5.709	3.169	0.0000000	0.0000000
DSP	-5.691	5.536	0.0000000	0.0000000
FLG	-5.622	4.183	0.0000002	0.0000032

Volcano Plot

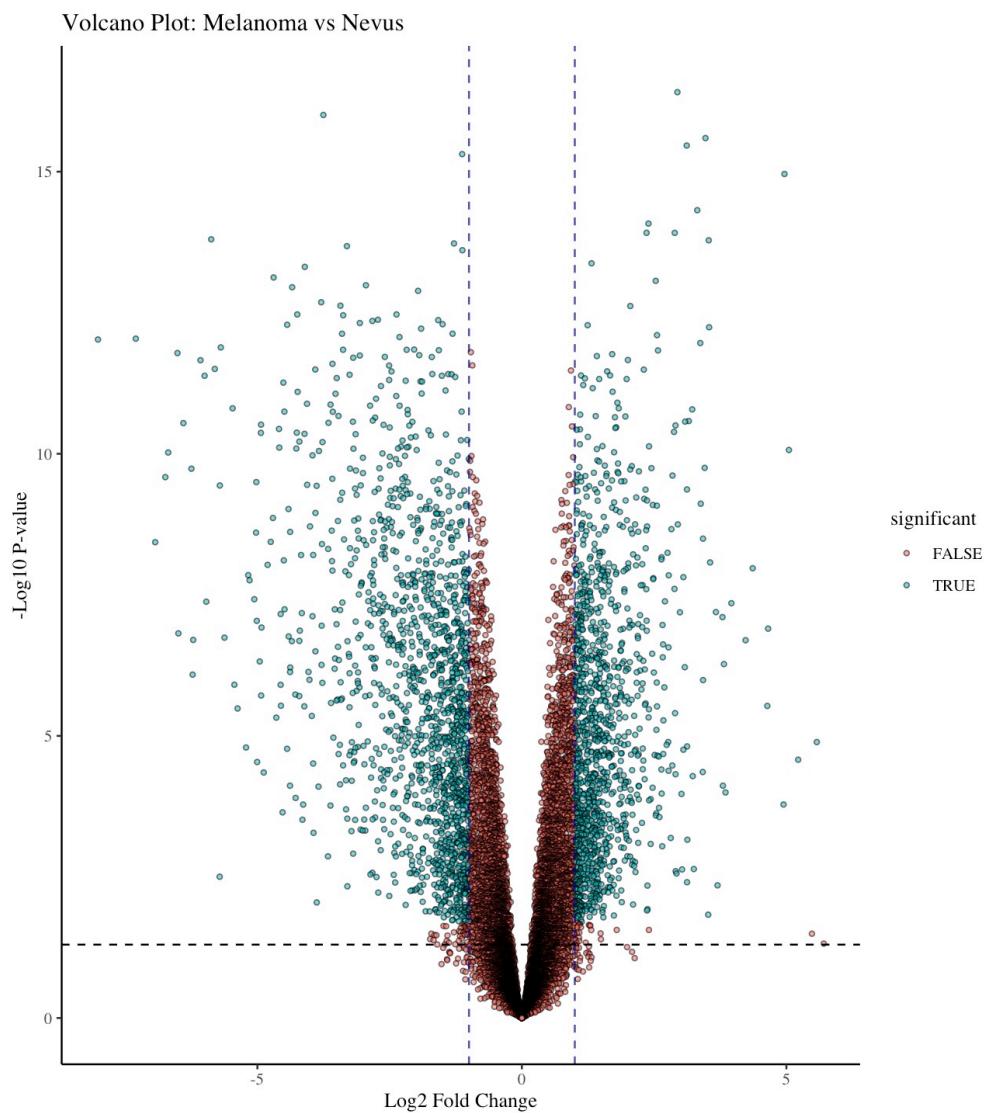


Figure 8: Volcano Plot I

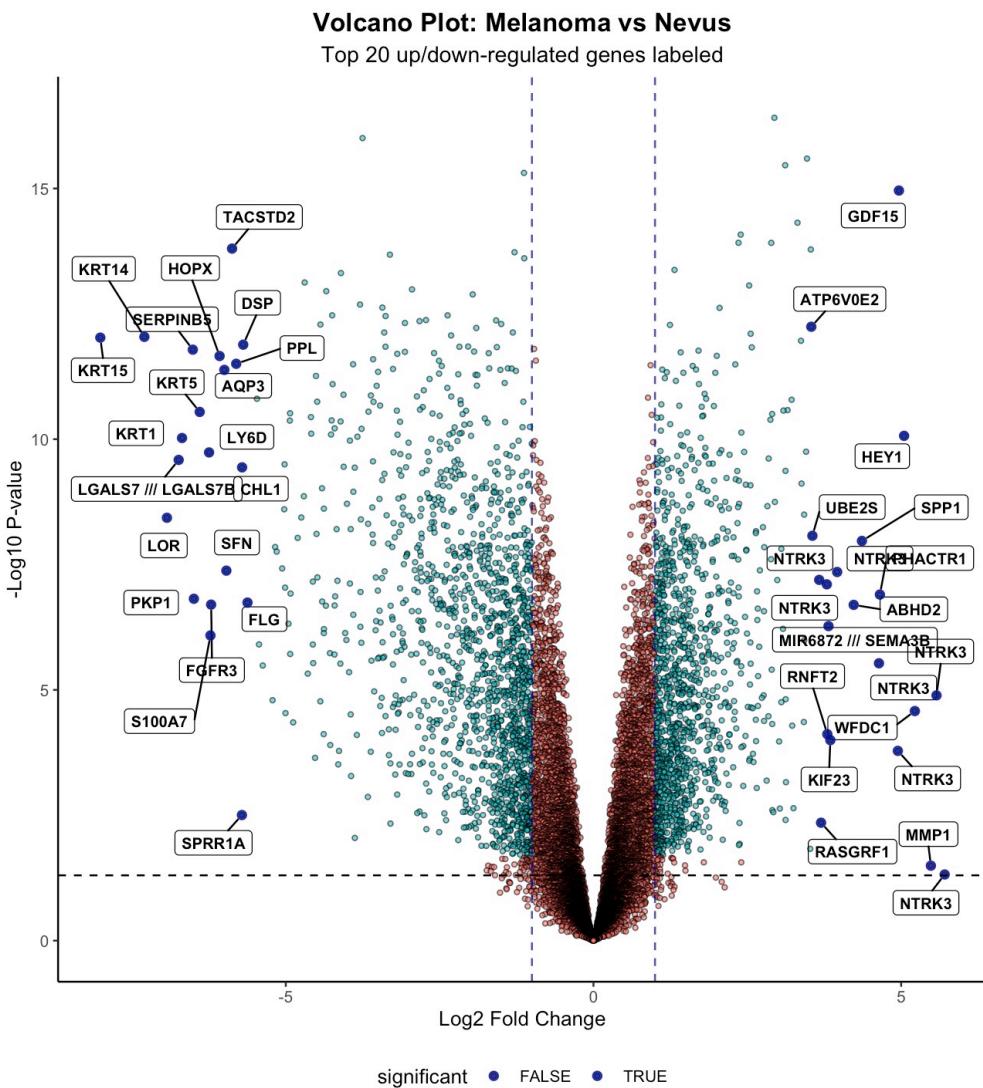


Figure 9: Volcano Plot II

MA Plot

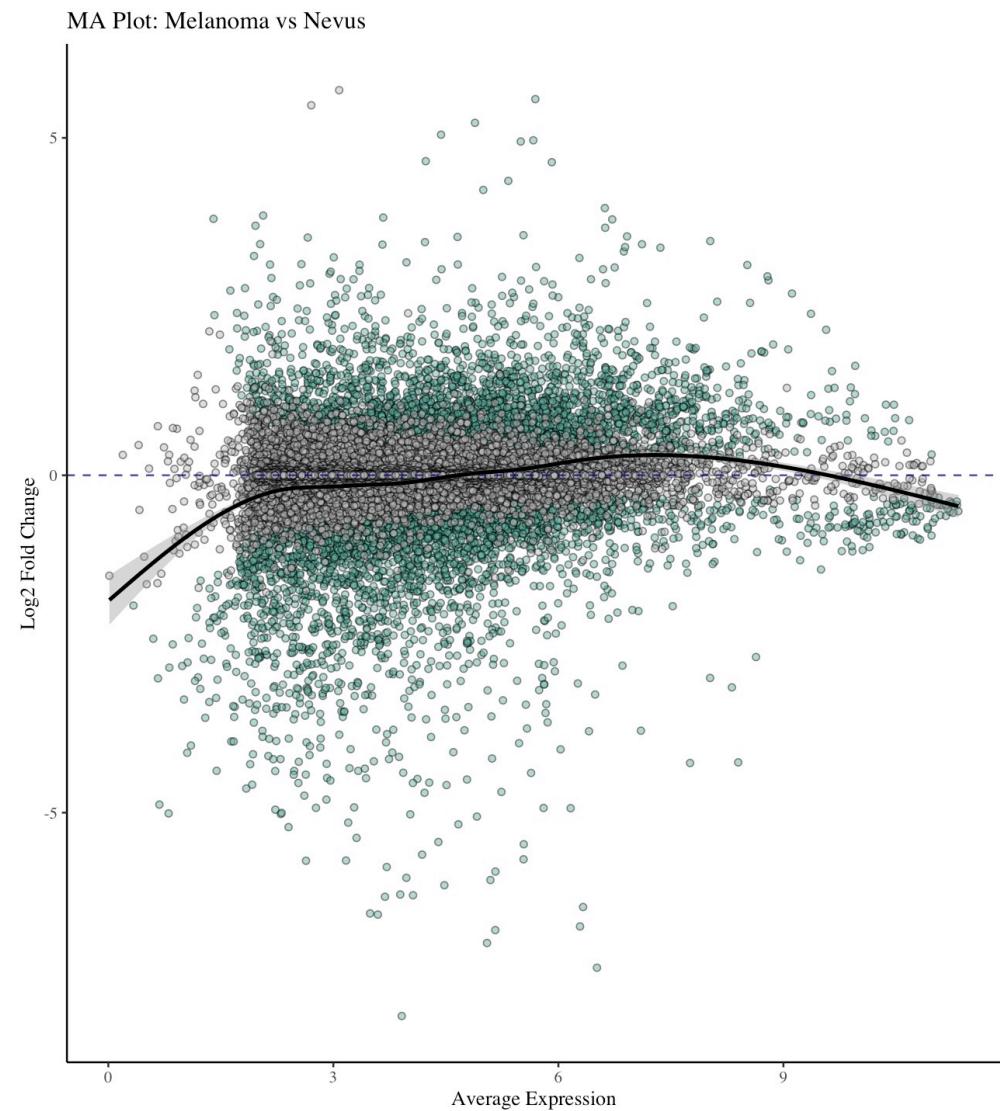


Figure 10: MA Plot

Principal Component Analysis (PCA) & Clustering

Sample Correlation Heatmap

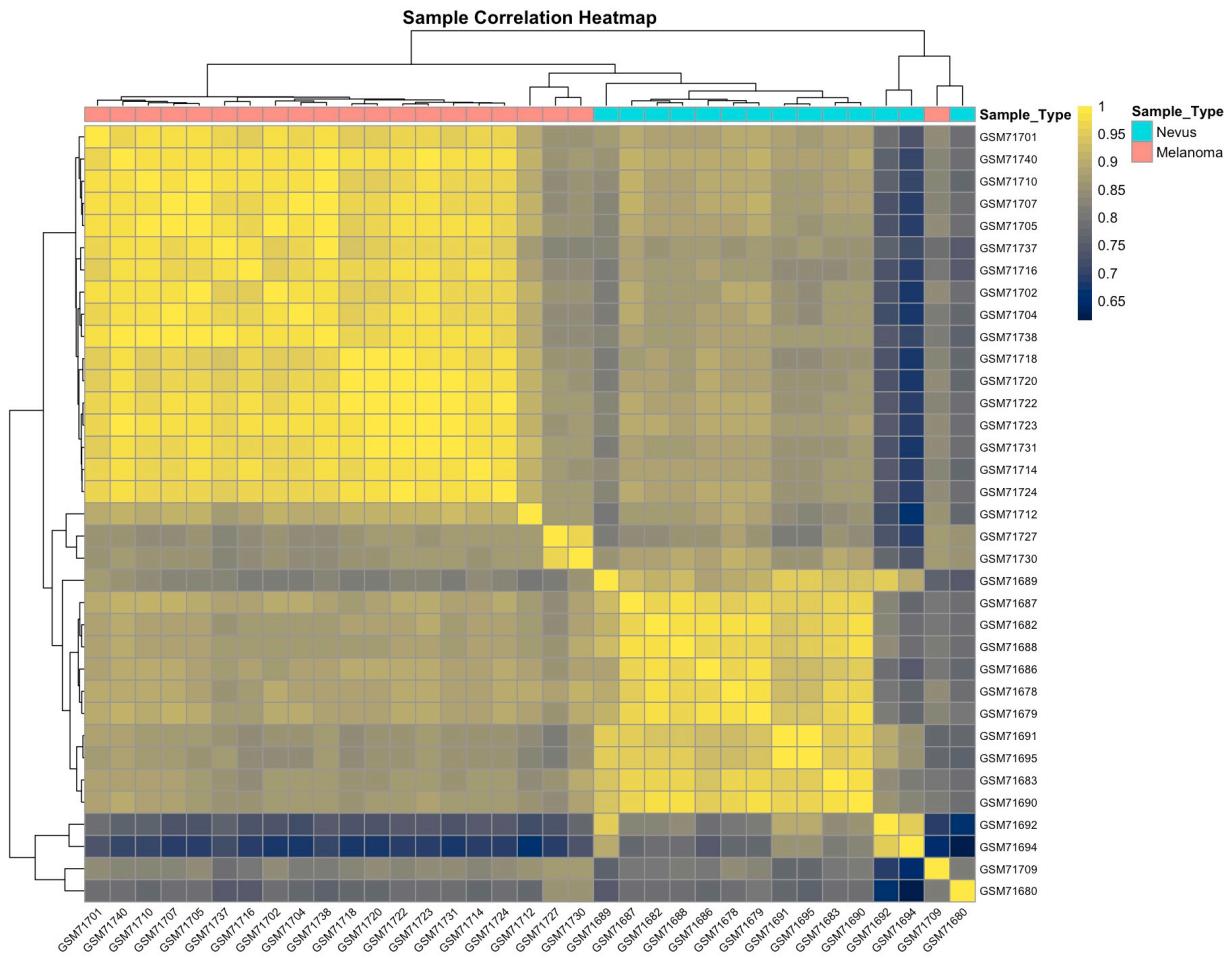


Figure 11: Sample Correlation Heatmap

This heatmap shows the pairwise correlations between the samples in the dataset. Yellow signifies a strong correlation and blue signifies no correlation. The rows and columns represent the same set of samples. Samples are hierarchically clustered based on their correlation. Similar samples are grouped together. However, there is 1 melanoma sample that is clustering with the nevi skin samples.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a dimensionality reduction technique used to simplify complex datasets by transforming correlated variables into a smaller set of uncorrelated variables called principal components.

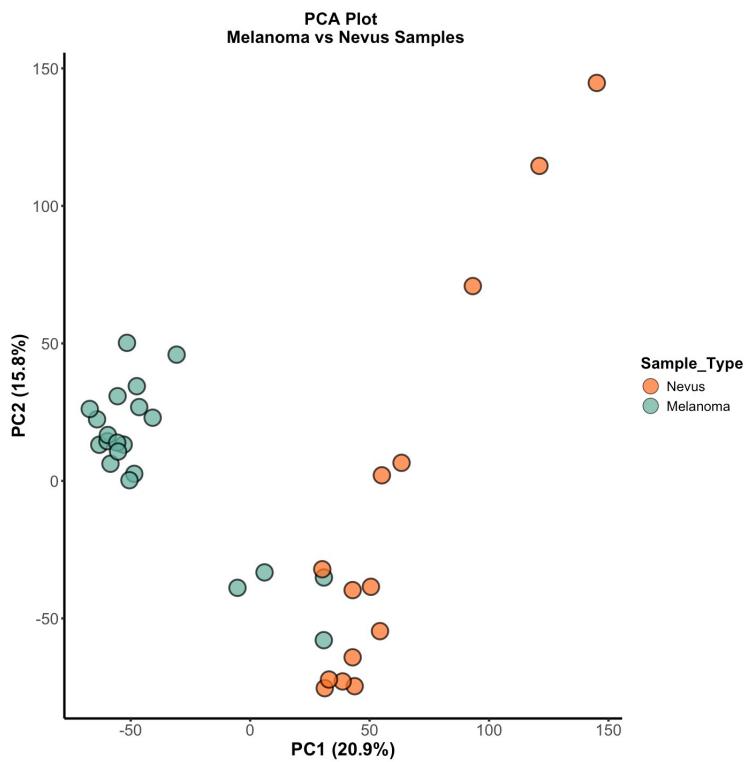


Figure 12: Principal Component Analysis (PCA)

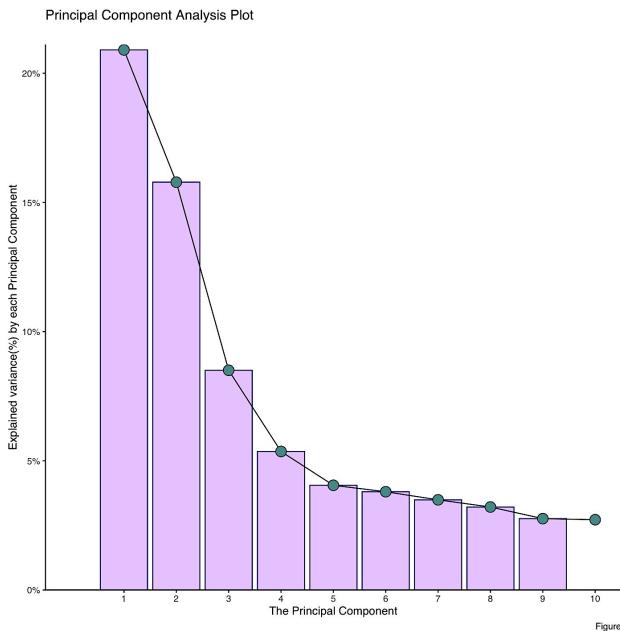


Figure 13: Scree Plot

Uniform Manifold Approximation and Projection (UMAP)

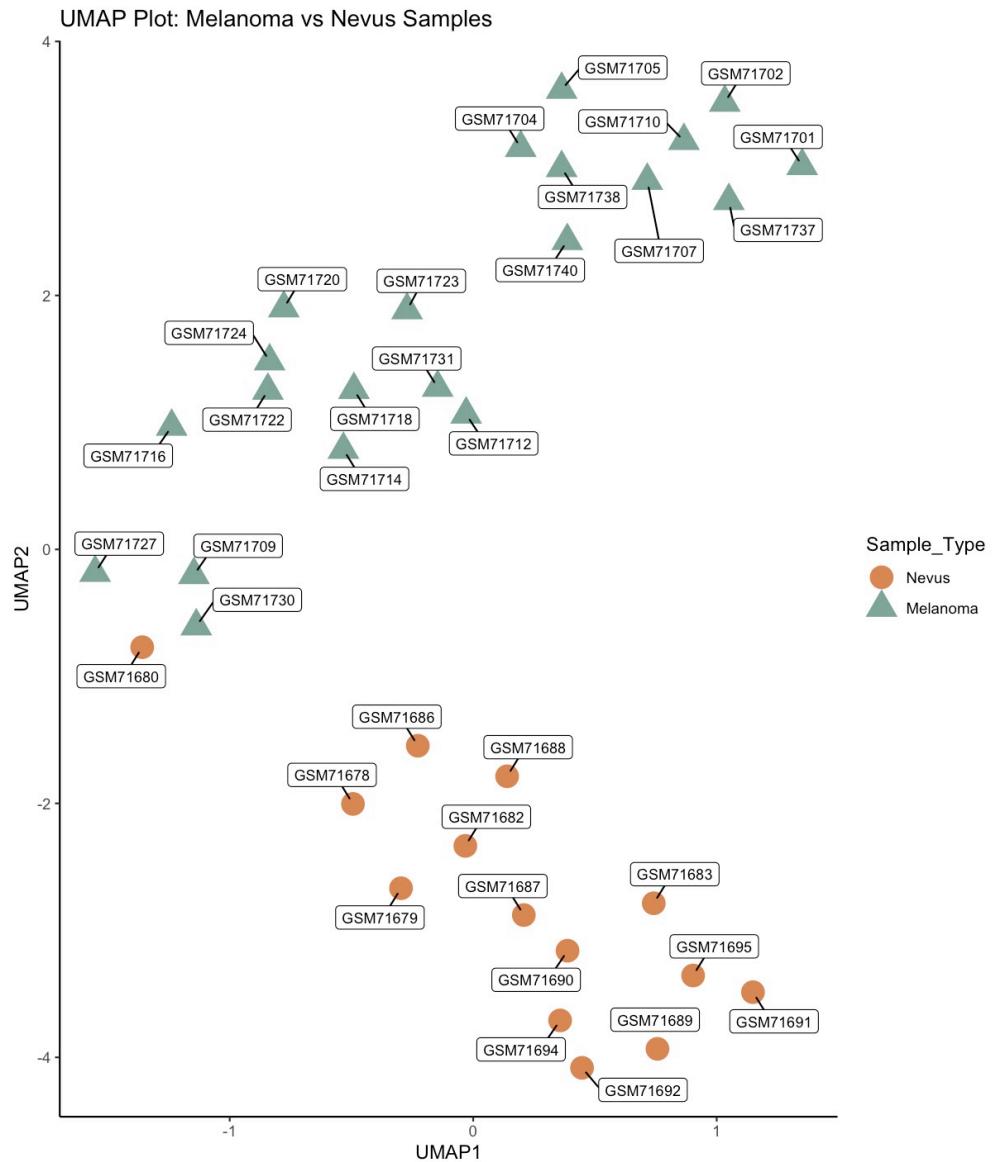


Figure 14: Uniform Manifold Approximation and Projection

Pathway Analysis

KEGG / GO enrichment KEGG pathways identified to look at genes in melanoma samples Biological Process and Pathway Analysis

The clusterProfiler package was used for pathway analysis.

Top GO Biological Processes

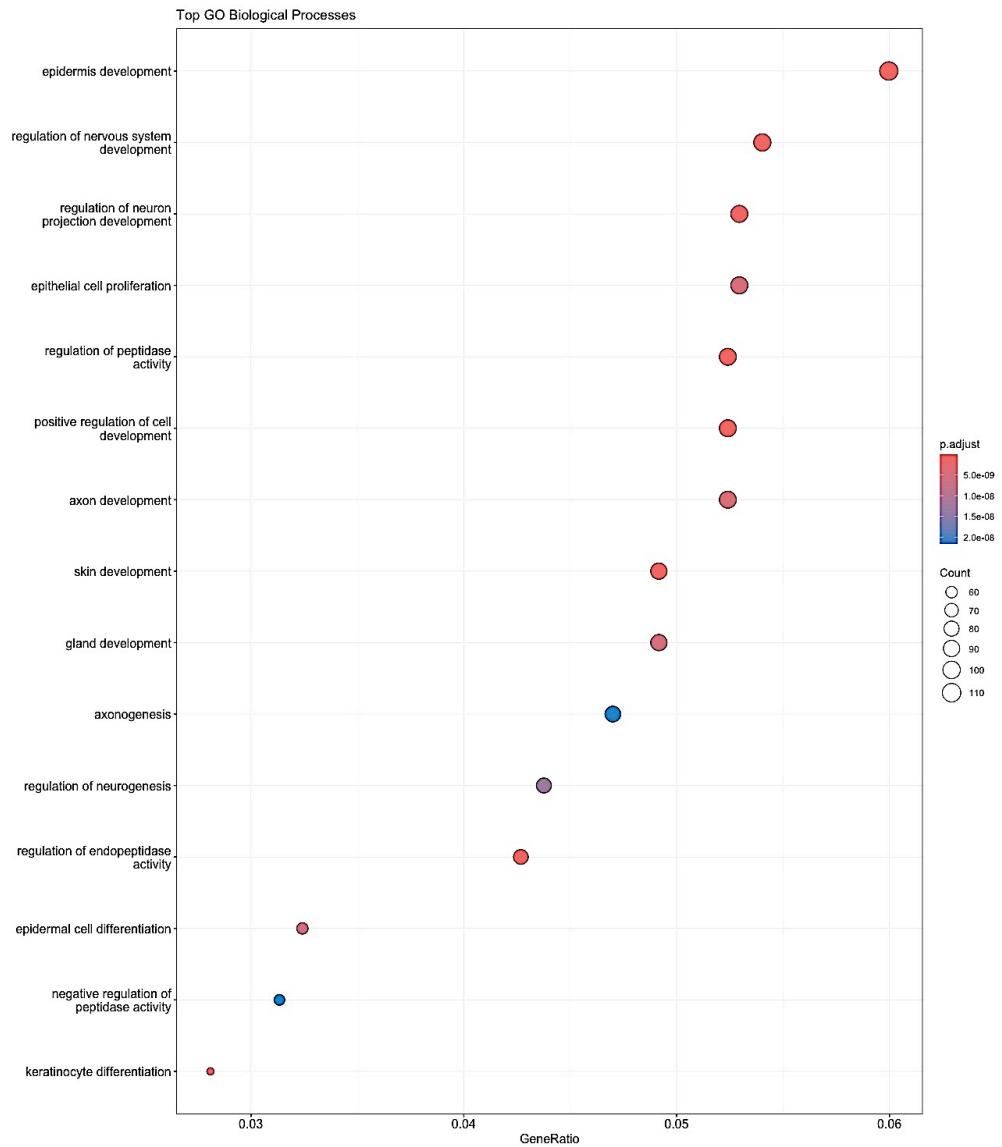


Figure 15: Gene Ontology Biological Processes

Top KEGG Pathways

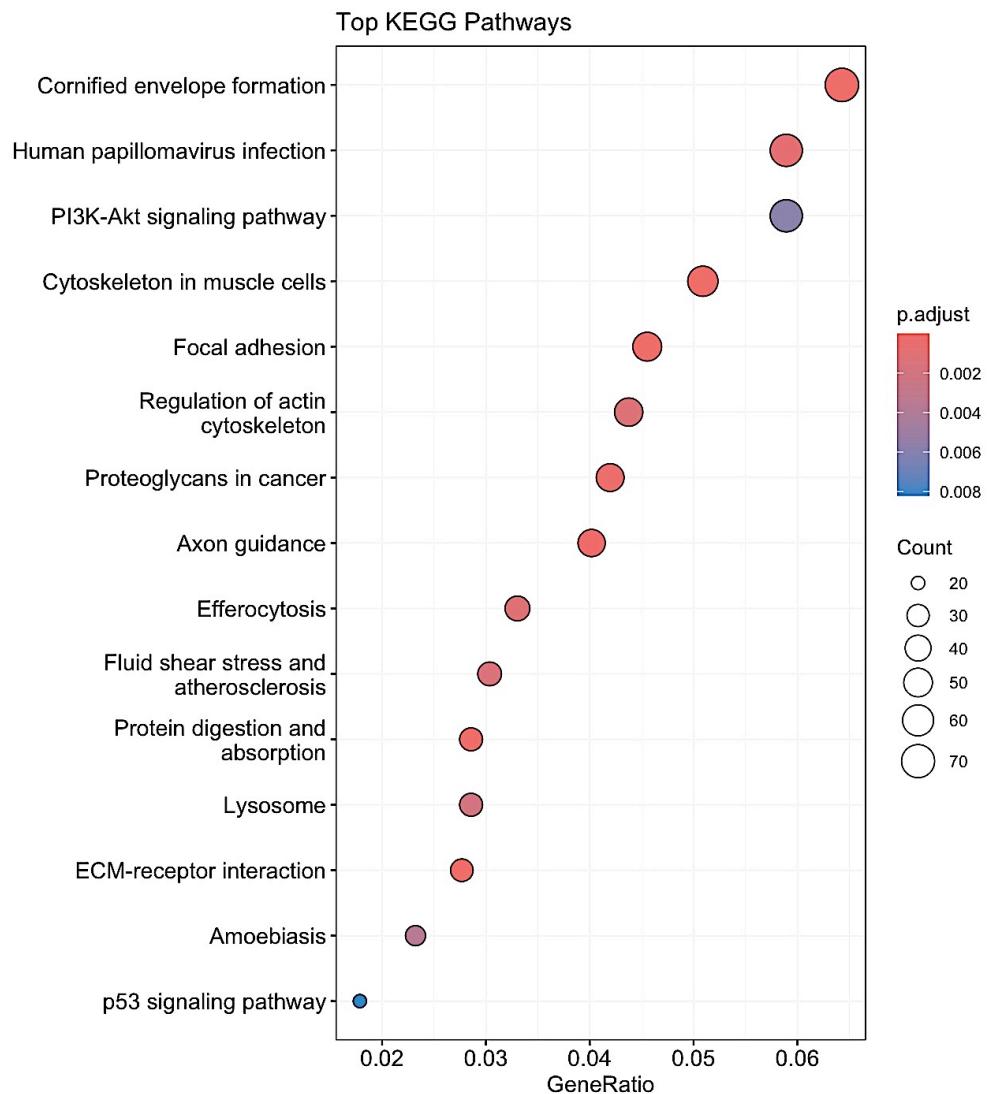


Figure 16: KEGG Pathways

Gene Signature Enrichment

- GSVA / ssGSEA results
- GSVA to perform ssGSEA analysis on signature genes with GSVA Package.

Table 3: (ssGSEA Enrichment Summary)

Gene Set	Mean Difference (Mel-Nevus)	P-value	Adjusted P-value	Significance
Melanoma Upreg Top20	0.524	1.51e-14	4.53e-14	Higher enrichment in Melanoma
Melanoma Downreg Top20	-0.7301	1.12e-10	1.68e-10	Lower enrichment in Melanoma
All Top DE Genes	-0.0661	1.08e-02	1.08e-02	Lower enrichment in Melanoma (small diff)

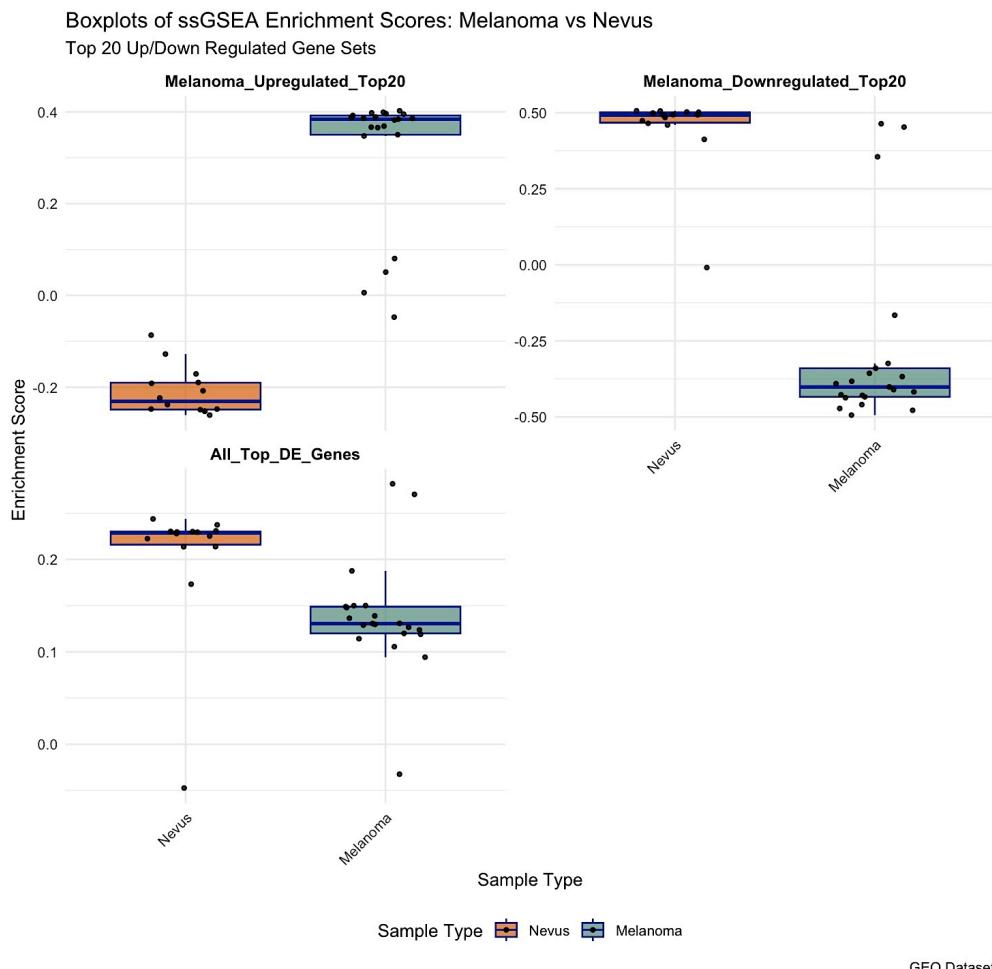


Figure 17: ssGSEA Enrichment Scores

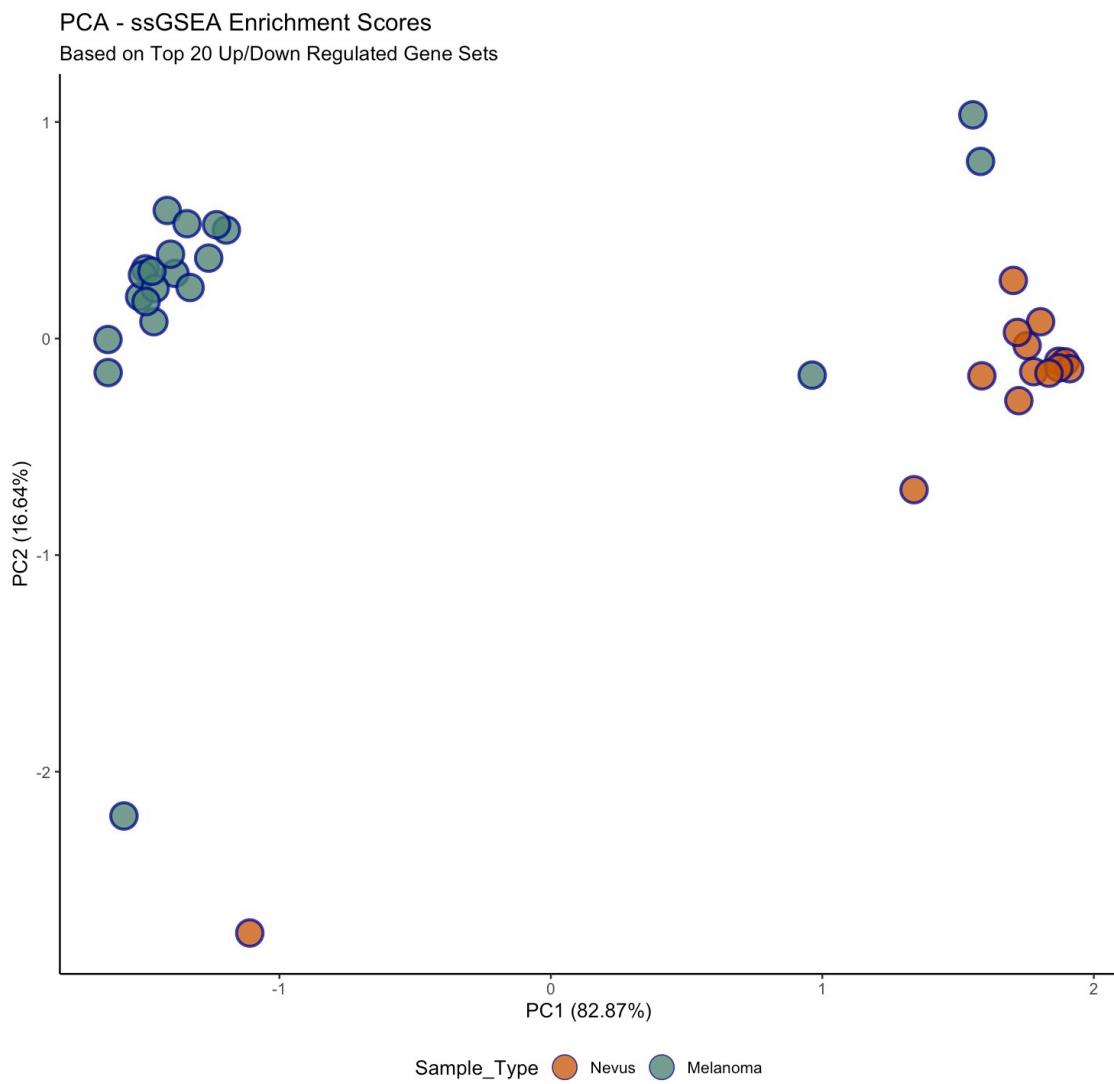


Figure 18: PCA from GSVA

Tumor Purity Estimation for Melanoma vs Nevus Samples

Table 4: (ESTIMATE Score Comparison: Melanoma vs Nevus)

Score	Melanoma_Mean	Nevus_Mean	P_Value
StromalScore	-602.188	-486.441	0.6347
ImmuneScore	-302.864	-505.272	0.5063
ESTIMATEScore	-905.052	-991.713	0.8710
TumorPurity	0.869	0.879	0.8334

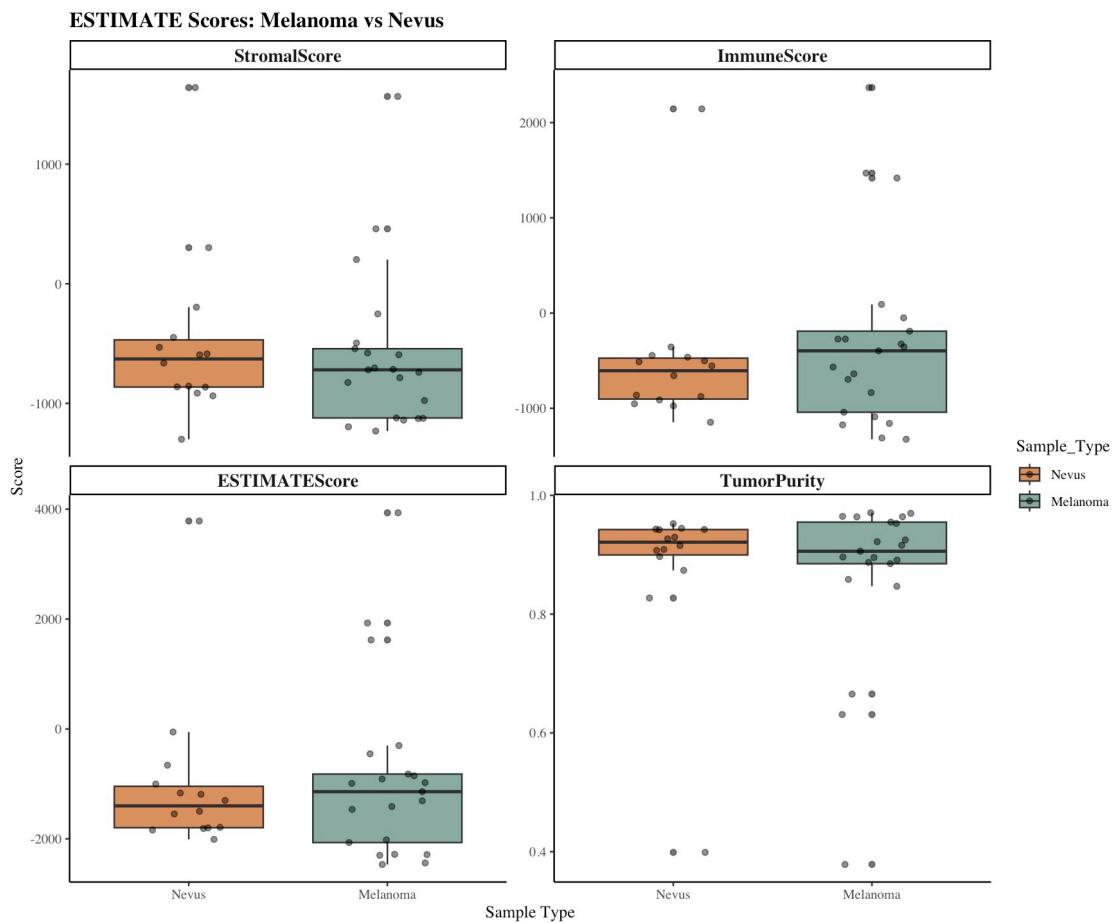


Figure 19: ESTIMATE Scores

RESULTS -- Topic II: *Streptococcus pyogenes*

Sequence Dataset Overview

Summary table of GAS strains and emm genes.

Table 5: (Table of *Streptococcus pyogenes* genomes)

Name.	Accession Number	Strain	Collection Date	Link
S. Pyogenes	AE014074.1	MGAS315	31-JAN-2014	https://www.ncbi.nlm.nih.gov/nuccore/AE014074.1
S. Pyogenes	CP000017.2	MGAS5005	01-APR-2014	https://www.ncbi.nlm.nih.gov/nuccore/CP000017.2
S. Pyogenes	CP155740.1	1851/03	06-AUG-2024	https://www.ncbi.nlm.nih.gov/nuccore/CP155740.1

Table 6: (Table of *Streptococcus pyogenes* emm genes) *Streptococcus pyogenes* emm gene for M protein, complete cds of various strains – Collection Date: 15-JAN-2014

Accession Number	Gene Name	Strain	Link
AB548437.1	emm1 gene for M protein	RE014	https://www.ncbi.nlm.nih.gov/nuccore/AB548437.1
AB548438.1	emm28 gene for M protein	RE015	https://www.ncbi.nlm.nih.gov/nuccore/AB548438.1
AB548441.1	emm1 gene for M protein	RE020	https://www.ncbi.nlm.nih.gov/nuccore/AB548441.1
AB548442.1	emm1 gene for M protein	RE025	https://www.ncbi.nlm.nih.gov/nuccore/AB548442.1
AB548444.1	emm28 gene for M protein	RE031	https://www.ncbi.nlm.nih.gov/nuccore/AB548444.1
AB548445.1	emm1 gene for M protein	RE032	https://www.ncbi.nlm.nih.gov/nuccore/AB548445.1
AB548446.1	emm49 gene for M protein	RE037	https://www.ncbi.nlm.nih.gov/nuccore/AB548446.1
AB548447.1	emm49 gene for M protein	RE039	https://www.ncbi.nlm.nih.gov/nuccore/AB548447.1
AB548448.1	emm28 gene for M protein	RE041	https://www.ncbi.nlm.nih.gov/nuccore/AB548448.1
AB548449.1	emm89 gene for M protein	RE050	https://www.ncbi.nlm.nih.gov/nuccore/AB548449.1
AB548450.1	emm1 gene for M protein	RE059	https://www.ncbi.nlm.nih.gov/nuccore/AB548450.1
AB548451.1	emm12 gene for M protein	RE066	https://www.ncbi.nlm.nih.gov/nuccore/AB548451.1
AB548452.1	emm49 gene for M protein	RE076	https://www.ncbi.nlm.nih.gov/nuccore/AB548452.1
AB548453.1	emm49 gene for M protein	RE080	https://www.ncbi.nlm.nih.gov/nuccore/AB548453.1
AB548454.1	emm49 gene for M protein	RE104	https://www.ncbi.nlm.nih.gov/nuccore/AB548454.1

Accession Number	Gene Name	Strain	Link
AB548456.1	emm49 gene for M protein	RE121	https://www.ncbi.nlm.nih.gov/nuccore/AB548456.1
AB548503.1	emm4 gene for M protein	RE342	https://www.ncbi.nlm.nih.gov/nuccore/AB548503.1
AB548508.1	emm12 gene for M protein	RE366	https://www.ncbi.nlm.nih.gov/nuccore/AB548508.1
AB548516.1	emm75 gene for M protein	RE436	https://www.ncbi.nlm.nih.gov/nuccore/AB548516.1
AB549960.1	emm58 gene for M protein	RE614	https://www.ncbi.nlm.nih.gov/nuccore/AB549960.1

Table 7: (Outgroup: *Streptococcus pyogenes* emm50 type - emm gene for M protein, partial cds. of various strains – Collection Date: 26-JUN-2013

Accession Number	Gene Name	Strain	Link
JX028641.1	emm gene, emm50 type	GLS244	https://www.ncbi.nlm.nih.gov/nuccore/JX028641

Phylogenetic Analysis using PAUP

The FASTA-formatted gene sequences were initially downloaded and subsequently renamed according to a standardised naming convention, incorporating the strain identifier, Genbank accession number, and gene name. This nomenclature facilitated consistency and traceability throughout the downstream analysis.

The individual FASTA files were concatenated into a single file using a Bash shell command as shown below:

```
cat * > ./emm.fasta
```

The resulting emm.fasta file was then opened in AliView for inspection and manual verification. During this process sequence headers were further edited to ensure uniqueness and clarity.

To perform multiple sequence alignment , the software **MUSCLE** was employed using the following command:

```
muscle -in emm.fasta -out emm_aligned.fasta
```

The aligned sequences (emm_aligned.fasta) were again viewed in AliView to assess alignment quality and make any necessary further adjustments²⁸.

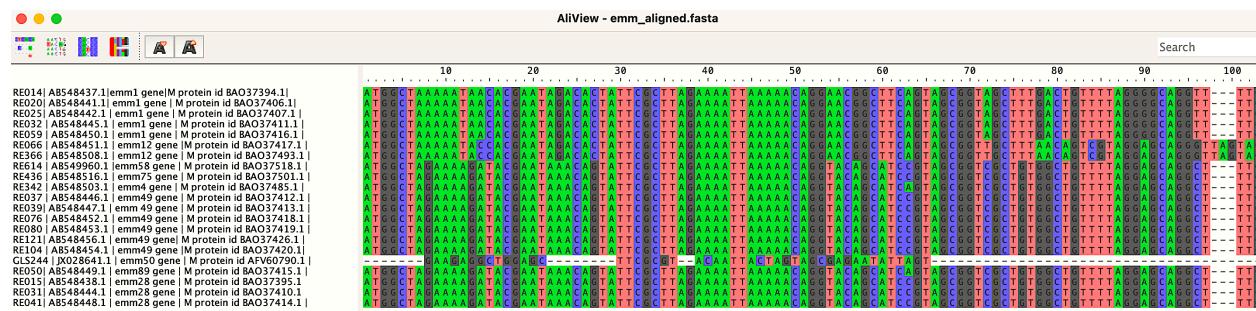


Figure 20: AliView

Following alignment the file was converted into NEXUS format for phylogenetic analysis using a custom Python script seqconverter.py²⁹ in conjunction with the sequenclib.py .

The phylogenetic analysis was carried out in PAUP* software³⁰ using the sequence labelled as GLS244 as the designated outgroup.

```
PAUP
execute emm.nexus
showmatrix
outgroup GLS244
```

A consensus tree was subsequently generated and visualised using FigTree³¹, allowing for a clear interpretation of the evolutionary relationships among the sampled strains.

```
set root=outgroup outroot=monophyl
contree all /strict=no majrule=yes percent=50
savetrees from=1 to=1 file=consensus_tree.tre format=newick brlens=yes;
figtree consensus_tree.tre
```

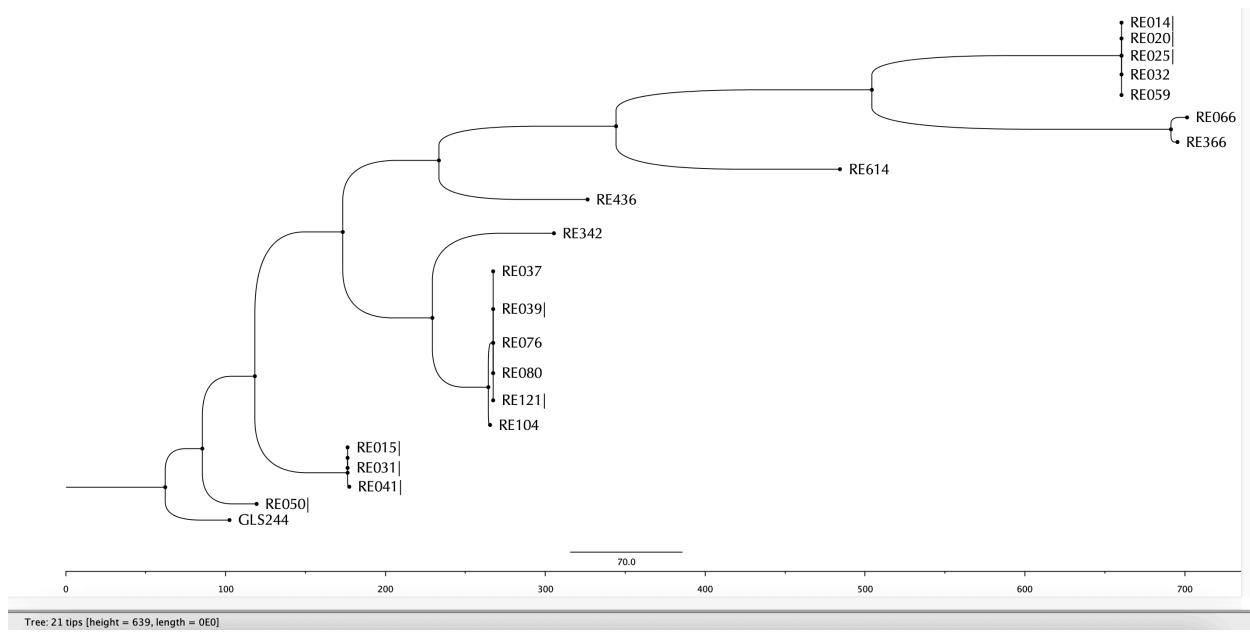


Figure 21: Consensus Tree

WebLogo

To investigate patterns of sequence conservation and variability, a sequence logo was generated using the aligned sequences as input. This visualisation facilitated the identification of conserved motifs and regions of high sequence variability. The sequence logo revealed that the conservations was primarily limited to the N-terminal and C- terminal regions while the central portion of the alignment exhibited variation.

For clarity and relevance, only representative segments of the logo corresponding to the highly conserved and highly variable regions are presented herein, rather than displaying the full alignment.

These patterns support the interpretation that conserved regions may be subject to purifying selection and thus potentially involved in essential structural or functional roles. In contrast, variable regions may reflect positive selection pressures, possibly contributing to immune evasion mechanisms in the host-pathogen interaction.

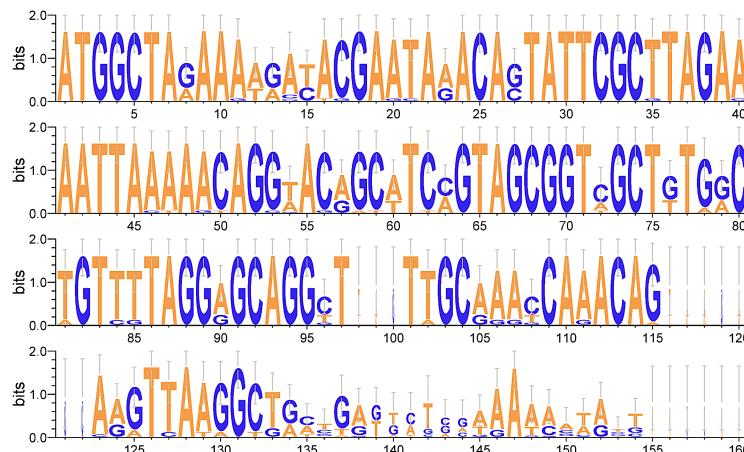


Figure 22: Sequence Logo 1

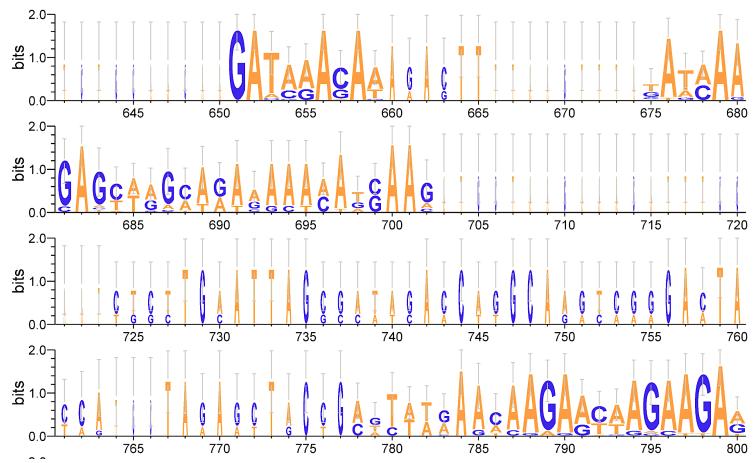


Figure 23: Sequence Logo 2

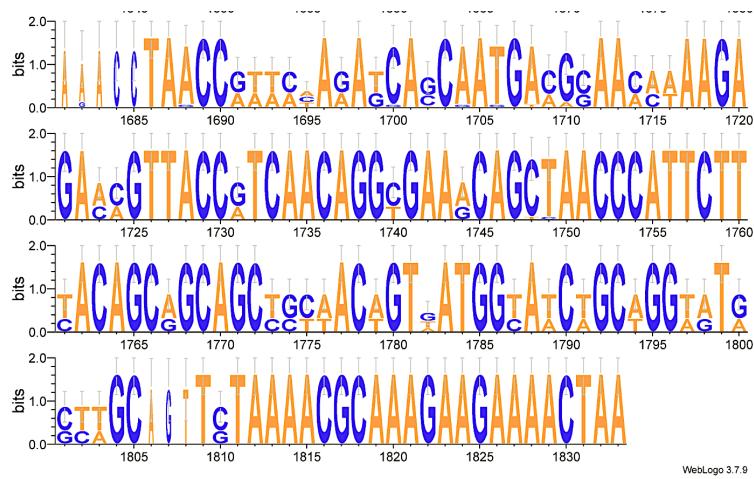


Figure 24: Sequence Logo 3

AlphaFold three-dimensional protein structure prediction

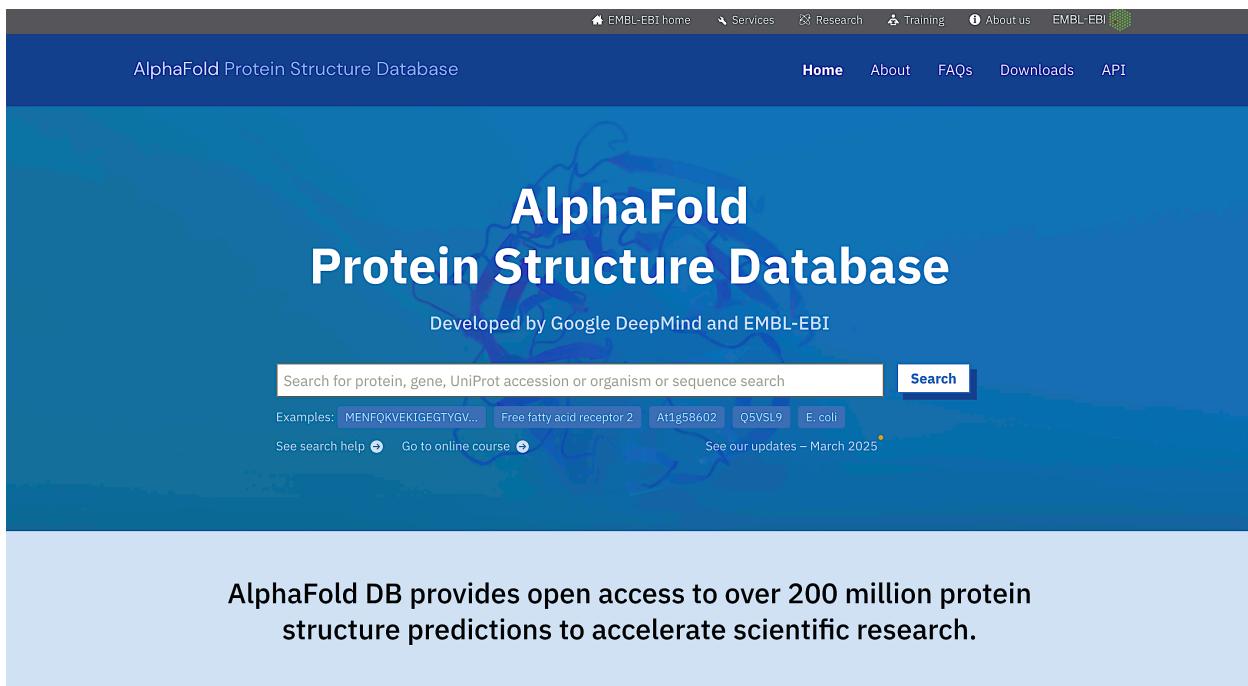


Figure 25: AlphaFold

Based on the amino acid sequence provided in the original FASTA file, the corresponding M protein sequence was retrieved in FASTA format.

To predict the three-dimensional structure of the M protein, the amino acid sequence was submitted to AlphaFold, which uses deep learning to infer protein folding patterns.

A BLASTP search was performed against the protein structure database to identify homologous structures. The search returned a 100% identity match with a known M protein sequence in UniProt (accession W0T1Y4).

The predicted structure was examined using PyMOL, a molecular visualisation system. Screenshots of the structural model of the M Protein are provided below³².

The M protein is encoded by the emm28 gene from *Streptococcus pyogenes*, has a UniProt ID of W0T1Y4, consists of 393 amino acids in length, and is identified in the Protein Data Bank as AF-W0T1Y4-F1-v4.

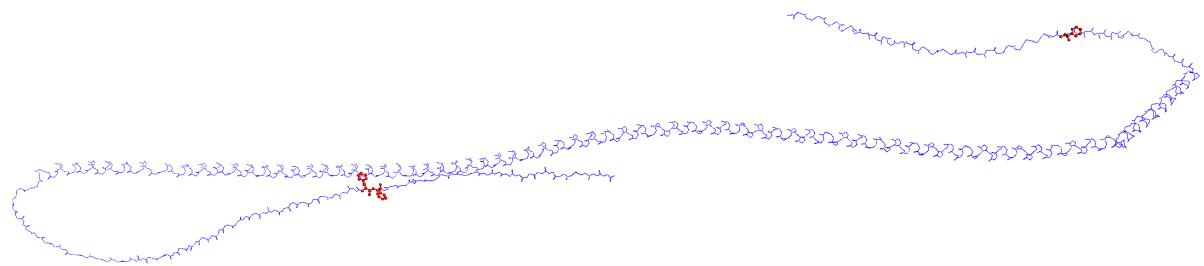


Figure 26: M Protein expressed from emm28 gene - Pymol

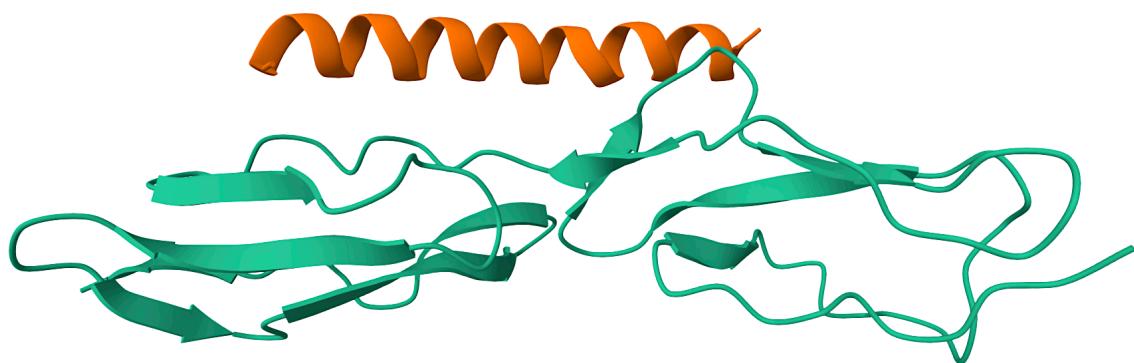


Figure 27: M Protein expressed from emm28 gene from UniProt

CHAPTER V: CONCLUSION

This bioinformatic investigation examined differential gene expression profiles between melanoma and nevus skin samples, using analytical approaches to reveal molecular signatures and pathways associated with Melanoma. The thesis contains various visualisation methods and uses computational tools to identify specific genes and characterise the underlying biological processes governing the transition from benign to malignant skin lesions.

The differential expression analysis revealed distinct molecular signatures distinguishing melanoma from nevus samples. Volcano plot visualisation demonstrated clear separation of significantly up-regulated and down-regulated genes, with \log_{10} p-values plotted against \log_2 fold changes revealing robust statistical significance. Among the most prominently unregulated genes in melanoma samples were NTRK3, RASGRF1, SPP1, HEY1, GDF15, and BCL2A1, while genes including KRT15, SERPINB5, LY6D, HOPX, SFN, CHL1, and FLC exhibited significant down-regulation. These findings were corroborated by MA plot analysis, which confirmed the magnitude and significance of expression changes.

Principal Component Analysis revealed intriguing clustering patterns, with one melanoma sample demonstrating molecular similarity to nevus samples, suggesting potential transitional states or heterogeneity within the dataset. This observation was further supported by correlation heatmap analysis, where melanoma sample GSM71709 clustered with nevus samples GSM71680 and GSM71694, indicating shared expression profiles that may represent intermediate stages of transformation. UMAP dimensionality reduction analysis reinforced these findings, showing that nevus sample GSM71680 clustered proximal to multiple melanoma samples, implying potential early transformation characteristics or biological similarity.

Gene Ontology enrichment analysis identified several key biological processes significantly associated with the differentially expressed genes. The analysis revealed enrichment of processes related to epidermis development, regulation of nervous system development, neuron projection development, and epithelial cell proliferation, while keratinocyte differentiation pathways showed reduced enrichment. These findings suggest that melanoma development involves dysregulation of fundamental keratinocyte differentiation.

KEGG pathway analysis elucidated several crucial signalling cascades and biological processes altered in melanoma progression. Significantly enriched pathways included cornified envelope formation, PI3K-Akt signalling, focal adhesion, proteoglycans in cancer, axon guidance, and efferocytosis. Notably, genes associated with human papillomavirus infection were also enriched, which may have clinical relevance given the established relationship between HPV and various skin pathologies.

Gene Set Enrichment Analysis provided additional validation of the differential expression patterns through examination of predefined gene signatures. The analysis of the top 20 up-regulated genes in melanoma demonstrated significant enrichment with a mean difference of 0.524 and adjusted p-value of 4.53×10^{-14} , confirming a distinct melanoma-associated expression profile.

Tumour microenvironment analysis using the ESTIMATE algorithm provided insights into the cellular composition of the samples. Melanoma samples exhibited lower stromal scores, indicating reduced stromal cell infiltration, while demonstrating higher immune scores suggestive of increased immune cell presence. This pattern may reflect the inflammatory response associated with malignant transformation or immune surveillance mechanisms.

ESTIMATE scores, which integrate both stromal and immune components, were marginally elevated in nevus samples. Tumour purity assessment revealed high values (approximately 0.8) in both sample types.

The phylogenetic analysis revealed strain clustering based on emm gene types, with emm1 and emm12 strains forming distinct evolutionary clades, suggesting conservation of genetic features within specific emm classifications. Sequence alignment and WebLogo analysis of the M protein identified highly conserved regions at both N- and C-termini, which likely play crucial roles in structural stability and functional integrity. The identification of phenylalanine residues at terminal positions is particularly noteworthy, as these aromatic, hydrophobic amino acids are relatively uncommon and may contribute to important structural or binding functions. The hydrophobic nature of phenylalanine suggests potential roles in membrane anchoring, protein-protein interactions, or tertiary structure stabilisation.

The presence of sulphur containing residues in the M protein , likely cysteines, indicates the potential for disulphide bond formation, which is known to confer mechanical stability and is particularly relevant in skin and hair-associated proteins. The conservation of phenylalanine residues across multiple protein homologs implies strong evolutionary pressure for their maintenance, suggesting critical functional roles in protein folding, membrane association, or binding specificity. PyMOL visualisation confirmed the distinct positioning of these residues, potentially highlighting important binding or anchoring sites within the protein structure.

The molecular patterns observed in this study provide valuable insights into the complex biological processes underlying melanoma development and progression. However, several limitations must be acknowledged. The dataset contained only seven normal skin samples, which limited the statistical power for comprehensive comparisons with both nevus and melanoma tissues. Future investigations should incorporate larger, well-annotated cohorts including adequate numbers of normal skin samples to better delineate the molecular changes occurring during early-stage melanoma development. In conclusion, this comprehensive bioinformatic analysis has successfully identified distinct molecular signatures differentiating melanoma from nevus samples, revealed key pathways, and characterised the tumour microenvironment composition.

Appendices

Pymol Script to display M protein structure

```
# PyMOL script to display structure

# Hide everything first
hide everything

# Show the carbon backbone as thin wire
show wire, name CA
set stick_radius, 0.1, name CA

# Alternatively, you can show the entire backbone as thin wire:
show wire, backbone
set stick_radius, 0.1, backbone

# Select phenylalanine residues
select phe_residues, resn PHE

# Show phenylalanine residues as ball and stick
show sticks, phe_residues
show spheres, phe_residues

# Color phenylalanine residues orange
color orange, phe_residues

# Turn on valence display for phenylalanine residues
set valence, on, phe_residues

# Optional: Adjust sphere and stick sizes for better visualization
set sphere_scale, 0.3, phe_residues
set stick_radius, 0.15, phe_residues
```

Table: (Summary of MUSCLE Alignment Log for emm Genes Isolated from Streptococcus pyogenes)
 MUSCLE v3.8.1551 by Robert C. Edgar | <http://www.drive5.com/muscle>³³

Time	Memory	Iteration	Progress	Step
00:00:00	1 MB(0%)	1	100.00%	K-mer dist pass 1
00:00:00	1 MB(0%)	1	100.00%	K-mer dist pass 2
00:00:00	22 MB(0%)	1	100.00%	Align node
00:00:00	22 MB(0%)	1	100.00%	Root alignment
00:00:00	24 MB(0%)	2	100.00%	Refine tree
00:00:00	24 MB(0%)	2	100.00%	Root alignment
00:00:00	24 MB(0%)	2	100.00%	Root alignment
00:00:01	24 MB(0%)	3	100.00%	Refine biparts
00:00:03	24 MB(0%)	4	100.00%	Refine biparts
00:00:03	24 MB(0%)	5	100.00%	Refine biparts
00:00:03	24 MB(0%)	5	100.00%	Refine biparts

PAUP Tree statistics

Table 9: (Tree Statistics from the Consensus Tree)

Statistic	Value
Tree length	1336
Consistency index (CI)	0.8278
Homoplasy index (HI)	0.1722
CI excluding uninformative characters	0.7941
HI excluding uninformative characters	0.2059
Retention index (RI)	0.9095
Rescaled consistency index (RC)	0.7529

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