# Natural History of Syphilis

Syphilis is a multistage disease with diverse and wide-ranging clinical manifestations that vary depending on the stage of infection, which often includes overlapping phases. In our compartmental model, we represent the natural history of syphilis through XX distinct stages. These stages are defined based on clinical symptoms (which trigger care-seeking), infectiousness (the potential for transmission), and the associated risks of mortality and disability (which influence the burden of disease and costs).

>Khalil: For simplicity, we classify syphilis into two broad periods: early infection (within the first year after transmission) and late infection (beyond one year). Early infection is sexually infectious, while late infection is not. Vertical transmission from mother to unborn child is assumed to occur throughout the entire course of untreated disease, with the majority (approximately 75%) of such transmissions occurring during the early stage of infection.

## Primary syphilis:

Within the early infection period, we assume that **primary syphilis** is characterized by the development of a painless chancre (sore), which represents an initial local infection. The chancre typically resolves spontaneously without treatment, but the disease quickly becomes systemic as *T. pallidum* disseminates throughout the body. Individuals in the primary stage are sexually infectious, and care-seeking behavior varies. In heterosexual men, primary chancres most commonly occur on the penis, while 32-36% of homosexual men have chancres in less visible locations, including the rectum, anal canal, and oral cavity. For women, primary chancres are usually found on the labia or cervix. Due to the painless nature of the chancre and its potential location in inconspicuous sites, syphilis diagnosis in women and homosexual men is often delayed until later disease manifestations become evident.

* ***Primary incubation:*** *Primary syphilis occurs 21 days (3 to 90) days after exposure when the first chancre develops (1, 2)*
* Duration of chancre: 3-6 weeks *(1, 2),*  2-6 weeks (3, 4), 4-6weeks(5)
* Prop of msm with chancre in non-penile area *including the rectum, anal canal, and oral cavity.*: 32-36% (5)
* Prop of women with chancre in the labia or cervix
* ***Secondary incubation:****The treponemes proliferate in the chancre and are carried via lymphatics to the bloodstream, from which they disseminate throughout the body. The time at which the secondary lesions make their appearance basically depends on two factors: the virulence of the treponeme and the systemic response of the host.* *Secondary syphilis appears around 3 to 12 weeks from the disappearance of the chancre(1)*

## Secondary syphilis

We assume that **secondary syphilis** is characterized by systemic symptoms, with the most prominent clinical sign being a rash that can present in various forms. Similar to primary syphilis, the symptoms of secondary syphilis typically resolve spontaneously even without treatment. This stage is highly infectious, and we estimate that 70-80% of individuals with secondary syphilis experience symptoms, with a subset of them seeking care.

* Delay to heal in absence of treatment: 1-2months (3), within 3 months (5), *2–12 wk (2 wk–6 mos) (6)*
* Percent noticing the rash or other symptoms to seek care ???

## Early Latent

The latent phase begins when symptoms resolve but the individual remains infected, as confirmed by serologic testing. We assume that **early latent** syphilis refers to infections acquired within the past 12 months. Individuals in this stage remain sexually infectious, although less so than those in primary or secondary syphilis. Approximately 25% of individuals in the early latent phase may **relapse** to secondary syphilis, temporarily increasing their infectiousness and likelihood of seeking care.

* Proportion relapse: 25%
* About 90% of first relapses occur within 1 year, 94% occur within 2 years, and the rest occur over 4 years. (6)

## Late latent

**Late latent** syphilis is assumed to occur when the infection has persisted for more than 12 months. We assume that individuals with late latent syphilis are not sexually infectious, as they lack the lesions necessary to transmit the disease to sexual partners. Late in the latent stage of syphilis, clinical manifestations are lacking, but serological tests are still positive; however, the intensity of serological reactions decreases gradually. The pathogen may occasionally persist in the bloodstream, although in small numbers, and can cause vertical infection (transmission from the mother to the fetus), but this occurs only infrequently. At this stage, the infection is no longer communicable by sexual intercourse

## Neurosyphilis

We include a distinct stage in the model to represent central nervous system (CNS) involvement, known as neurosyphilis, which can occur at various points during disease progression. Neurosyphilis manifests in several clinical forms depending on the timing and affected area. For modeling purposes, we focus on symptomatic CNS involvement due to its significant impact on care-seeking behavior.

Early symptomatic neurosyphilis, such as meningeal neurosyphilis, typically occurs within the first year of infection and presents with symptoms like headaches, neck stiffness, nausea, photophobia, and cranial nerve involvement. Late symptomatic neurosyphilis forms include meningovascular neurosyphilis, which generally arises 5–12 years post-infection and is associated with ischemic strokes caused by inflammation of cerebral blood vessels. Additional late-stage forms include *tabes dorsalis*, characterized by severe pain, sensory ataxia, loss of proprioception, and Argyll Robertson pupils, as well as *general paresis*, which involves progressive cognitive decline, personality changes, psychosis, and motor deficits. Furthermore, ocular and otic neurosyphilis may lead to uveitis, optic neuropathy, hearing loss, tinnitus, or vertigo, potentially resulting in permanent disability if untreated.

## Tertiary:

Tertiary syphilis describes patients with late syphilis who have **symptomatic** manifestations involving the cardiovascular system or gummatous disease (granulomatous disease of the skin and subcutaneous tissues, bones, or viscera) or neurologic involvement. Appearance of these presentations is dependent on where T.Palldium dissemination occurs within the body

Cardiovascular syphilis typically presents with complications such as aortic aneurysms, aortic regurgitation, and coronary artery ostial stenosis. Gummatous syphilis is characterized by granulomatous, nodular lesions, which, although rare, can occur in various organs, most commonly the skin and bones. These lesions are generally benign unless their destructive effects involve vital organs, a condition often referred to as "late benign syphilis." (5) Late neurological manifestations of syphilis can also arise, including forms like tabes dorsalis and general paresis.

## Parametrizing CNS and Tertiary syphilis rates:

To estimate the rate of progression from each stage of syphilis, we calculate the proportion of patients experiencing specific outcomes over a given timeline. This is achieved using the following formula:

Exponential rate (λ)=−ln(1−probability)/time span

Here:

* **Probability** refers to the likelihood of progression to a specific stage or clinical manifestation of syphilis (e.g., CNS involvement or tertiary syphilis).
* **Time span** represents the period over which the progression occurs (e.g., from early to late stages of syphilis).

Historical data provides insights into the progression of late syphilis.

* The Oslo Study, a prospective natural history study conducted from 1891 to 1951, followed 1,978 patients with primary or secondary syphilis. It reported a mortality rate of 17% for males and 8% for females, with **28%** of patients eventually developing clinically evident complications of late disease. These complications included **cardiovascular syphilis (10%),** **symptomatic neurosyphilis (65%),** and **late benign syphilis (16%).** Cardiovascular syphilis and neurosyphilis were observed more frequently in males, and autopsy findings often revealed evidence of cardiovascular involvement.
* Paul Rosahn's review of autopsy findings at Yale University (1917–1941) showed that 9.7% of individuals over 20 years old had clinical, laboratory, or autopsy evidence of syphilis, with about half untreated. Among syphilitic patients, 51% had specific late syphilitic lesions at autopsy, with **30%** of clinically diagnosed cases showing such lesions. Among 77 untreated cases with late syphilitic lesions, **83% were cardiovascular**, **7.6% neurological**, and **8.5% gummatous**. These manifestations generally appeared 15–30 years after the initial infection, often involving multiple overlapping symptoms.

### Probability of Developing Early CNS (P1-P2,P3)

**Golden (2003) & Kent (2008)** estimate that 25–60% of patients experience CNS invasion during the primary and secondary stages, with 5% of these cases being symptomatic. This results in an estimated [1.25–3%] of all patients developing symptomatic CNS disease.(2, 7)

### Probability of Developing Late Neurosyphilis & Tertiary Disease (P4,P5)

In the **Oslo Study (cited in Kent2008):** Eventually, 28% of patients developed clinically evident complications of late disease including cardiovascular syphilis (10%), symptomatic neurosyphilis(65%), or late benign syphilis (16%), with both cardiovascular and neurosyphilis occurring more commonly in males

* + If I multiple these proportions into 28% to approximate total proportions:  2.8% of patients developing cardiovascular syphilis, 4.5% developing late benign syphilis, and 18.2% developing symptomatic neurosyphilis

* **Boeck study (cited in Singh1999)** estimates that approximately 30% of the patients developed tertiary manifestations. Late benign syphilis was the most frequent manifestation, occurring in 14% of males and 17% of females, 1 to 46 years after healing of the secondary lesions. The incidence of clinically apparent cardiovascular syphilis was 13.6% in males and 7.6% in females, but the true incidence may have been higher had more autopsies been carried out. Symptomatic neurosyphilis developed in approximately 9.4% of males and 5.0% of females.
  + It’s unclear to me if the final proportions are after factoring in the 30% or not. I assume that they are.  However, these proportions are in contrast to Oslo’s study finding the majority of Tertiary cases as symptomatic neurosyphilis

* **Lanford (2006)** estimates the following proportions from the literature: Progressive inflammation caused gumma (late benign syphilis) in 15% of patients with untreated syphilis. Cardiovascular syphilis was observed in 10% of untreated patients. Symptomatic late neurosyphilis was recognized in 6.5% of untreated patients.
  + These results are inline with Boeck study

* **Golden (2003)** provides an estimate for the two forms of tertiary syphilis, at 2-5% over 20-30 years developing General Paresis, and 2-9% over 3-50 years developing Tabes Dorsalis, but it’s progressed among those with early CNS (25-60%)
  + This is approximately, 4-14% of those patients with early CNS>> 2-5% of all patients?

Final thoughts:

* Late benign syphilis: 14% of males and 17% of females, 1 to 46 years post infection (Kent-2008, Golden-2003)
* cardiovascular syphilis: 13.6% in males and 7.6% in females  10-30 years post infection (Kent-2008)
* Symptomatic neurosyphilis:  9.4% of males and 5.0% of females over 4-25 years post infection (Kent-2008)

# Infectiousness

The infectiousness levels of syphilis vary across its stages, driven by clinical manifestations and the presence of lesions that facilitate transmission. During primary syphilis, infectiousness is high due to chancres, which are teeming with *Treponema pallidum*. This risk peaks in secondary syphilis, characterized by mucocutaneous rashes and condylomata lata, both rich in bacteria and highly transmissible. Early latent syphilis retains moderate infectious potential, with occasional relapses of secondary symptoms. In contrast, late latent syphilis and tertiary syphilis are considered non-infectious due to the absence of active lesions. Congenital syphilis transmission, however, depends heavily on the maternal stage of infection, with the highest risk during early syphilis (within 12 months of infection) when bacterial loads are at their peak.

Secondary syphilis case patients also have infectious lesions (mucous patches and *condyloma lata*) which are present in approximately 30% of secondary case(8, 9)

Oxman Modeling: Primary 30%, secondary 75%

# Target

Diagnosis of PS, EL, Late or unkown: available through Atlas Plus

Individual reports include information on **Primary vs Secondary** diagnosis before 2017 and also diagnosis in STD clinic or non-STD clinic

A table with numbers and a number of people

Description automatically generated

Secondary: max =1

Primary Relative to secondary:

EL relative to secondary:

Diagnosis

We assume that there are two separate mechanisms for diagnosis:

**Screening**: This is based on underlying rates of STI screening among populations.

**Symptomatic Screening Rates**: These rates vary by syphilis stage—primary, secondary, tertiary, and CNS involvement.

For **primary syphilis**, the differential is higher among heterosexual men compared to MSM (men who have sex with men) and women.

**Secondary syphilis** has a higher symptomatic screening rate compared to primary syphilis.

The rates for **tertiary syphilis** and **CNS involvement** are the highest among all stages.

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