Evolution by transposition

Are genomes static? Do genomic segments retain their same location over time?
No!

Transposition: movement of genetic material from one chromosomal location (donor site) to another (target site)

Mobile or Transposable Elements: sequences with intrinsic capability to change genomic location

Evolution by transposition

"Mobile elements...are so ubiquitous, so diverse, and have such a profound effect on eukaryotic chromosomal architecture that an overview of genomic evolution ought to start with them, before moving on to the host gene themselves" - Lynch

Evolution by transposition

Discovery of transposable elements

Barbara McClintock in the 1940s - studies of maize

Evolution by transposition

How widespread are mobile elements?

*D. Melanogaster* has many copies of 50-100 different kinds of transposable elements

Evolution by transposition

How are mobile elements carried?

Can be integral to genome or can be carried by extra-chromosomal elements (plasmids or viruses)
Evolution by transposition

How autonomous are mobile elements?

Some are autonomous (encode transposase genes) some are not (recruit transposases from other mobile elements) and thus depend on their genetic background

Mobile element specificity

Species: some species specific, some not

Tissue: in animals, many mobile only in germ line

Sites: some insert to specific locations others at random

- Mu: totally random
- IS4: in E coli only in galactosidase operon
- Tn10: in E coli 40% in lacZ gene
- IS1: favors AT-rich insertion sites
- TRIM: preference for Y chromosome

Types of transposition

Conservative: element itself moves, “cut & paste”

Replicative: element is copied then moved, “copy & paste”

Elements can use one or both types of transposition

Classification of transposable elements

Insertion sequences

- Transposons (eg Drosophila P element)

Retrotransposons

- Retroviruses
- LTR
- Non-LTR (eg SINES and LINES)
Classification of transposable elements

Insertion sequences: ~700-2500 bp long, no genetic information beyond what is necessary for transposition

Classification of transposable elements

Transposons: mobile DNA elements, ~2500-7000 bp long, carry “exogenous genes” in addition to information necessary for transposition

Transposition is generally conservative “cut and paste” and does not involve an RNA intermediary

Classification of transposable elements

Retrotransposons: DNA elements containing gene for reverse transcriptase. They are transcribed into RNA then reverse-transcribed into cDNA

Retrotransposition is always replicative “copy and paste”

Types of transposition

Retrotransposition: element is copied to RNA then moved

The “copy and paste” mechanism means that birth of new elements leaves the parental copy intact and never leaving insertion site

Classes of retrotransposons

LTRs = long terminal repeats = key role in element proliferation

Retroviruses: make virion particles, have LTRs

Non-LTR retrotransposons: do not make virions, do not have LTRs

LTR retrotransposons: do not make virions, do have LTRs

Note there are also non-transposable retroelements and also retrosequences that do not make their own reverse transcriptase but use it from other retroelements (Table 7.1)
Classes of retrotransposons

**Retroviruses:** make virion particles, have LTRs

Subclass of non-LTR retrotransposons

**LINES:** long interspersed repetitive elements
Typically range in length from 3-7kb,
Active or degenerate copies of retrotransposons

**SINES:** short interspersed repetitive elements
Typically range in length from 75-500 bp,
Not autonomous

>1/3 human genome consists of interspersed repetitive sequences

Subclass of non-LTR retrotransposons

Many LINE/SINE couples have been identified

Classes of retrotransposons

**Non-LTR retrotransposons:** do not have LTRs

Mechanism for non-LTR replication is sloppy so new insertions deviate from parental elements

Because many copies are truncated, many insertions are “dead on arrival”

Number of active elements is small subset

Subclass of non-LTR retrotransposons

**LINES** can exist on their own but SINES cannot because they do not have their own self-replicating machinery. They need to make use of LINE-encoded reverse transcriptase

Classes of retrotransposons

**LTR retrotransposons:** do have LTRs

LTR element cDNA production is remarkably intricate and faithful process

Unlike non-LTR elements, newly produced LTR elements are 100% identical to parents

LTR element divergence thus happens after insertion and can be used to infer age of insertion
Fitness consequences of mobile elements

Selfish-DNA or “intragenomic parasites”: ability to replicate faster than host genome

In *Drosophila* rates of mobile element:

- insertion = \( \approx 1 \times 10^{-4} \)
- excision = \( \approx 4 \times 10^{-6} \)

So if transposable elements don’t contribute to run away genome sizes there must be something regulating their accumulation

Disadvantageous fitness effects:

Insertion into coding region can alter or obliterate reading frame

Excision can be imprecise causing additions or deletions

Deleterious changes in gene expression can be caused by transposon regulatory elements such as promotors

Some evidence for increased mutation rate following transposition

Extremely disadvantageous fitness effects:

*Hybrid dysgenesis*: abnormal genetic traits in hybrids due to single transposable element

Uncontrolled transposition of *P* element in *Drosophila* can lead to sterility and mortality

*P* element is thought to be kept “in check” by cytoplasmic repressors

*P* element is a recently acquired transposon from other *Drosophila* to *D. melanogaster* (possibly via tick vector) in the Americas and subsequent geographic spread

% *P* strains collected in wild
Host-encoded mechanisms: post-transcriptional gene silencing via RNAi (e.g., C. elegans that have lost RNAi have elevated rates of transposition)

Also some unusual mechanisms in particular groups (e.g., repeat induced point mutations RIP in the fungus Neurospora prevents proliferation)

Selection may oppose overly aggressive copies via:

Fitness consequences of mobile elements

Advantageous consequences:

Given the diversity of mutational types produced by mobile elements and their large contribution to the total mutation pool some insertions will be advantageous (due to changes in coding or regulatory sequences)

Also plenty of examples (mostly in bacteria) of antibiotic (or other resistance) conferred by mobile elements carried in plasmids

Summary

Why are transposable elements so common in nature?

Possibilities:

a) Confer a selective advantage on hosts (not generally)

b) Ability to replicate faster than host genome (likely)

c) Neutral, population size dependent behavior (likely)

Patterns of mobile element occurrence due to interaction between:

- Probability of proliferation
- Probability of excision
- Intensity of countervailing selection
- Efficacy of countervailing selection
- Strength of genetic drift

Horizontal gene transfer

Vertical gene transfer: transfer of genetic information from parent to offspring

Horizontal gene transfer: transfer of genetic information from one genome to another between two species (horizontal) or between individuals within species (lateral)

Long-term survival of mobile element families is dependent on rare horizontal transfers
Mechanisms of horizontal gene transfer

**Xenology**: sequence similarity due to horizontal gene transfer (in contrast to paralogy or orthology)

Can contribute to gene tree/species tree discrepancies

For next class
G+L chap 7