

# Horizontal Gene Transfer

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## DEFINITION AND BACKGROUND

Horizontal gene transfer (HGT) is the movement of genetic information between organisms, a process that includes the spread of antibiotic resistance genes among bacteria (except for those from parent to offspring), fueling pathogen evolution.

Many resistance genes evolved long ago in natural environments with no anthropogenic influence but these genes are now rapidly spreading to and among human pathogens. HGT occurs by three well-understood genetic mechanisms (Fig. 1):

- Transformation: Bacteria take up DNA from their environment
- Conjugation: Bacteria directly transfer genes to another cell
- Transduction: Bacteriophages (bacterial viruses) move genes from one cell to another

Once transferred, the genes and pathogens continue to evolve, often resulting in bacteria with greater resistance [1, 2, 3, 4]. All genes—not just those causing drug resistance—may be horizontally transferred and proliferate by natural selection, including virulence determinants [5].

## EXAMPLES IN HUMAN BIOLOGY AND PUBLIC HEALTH

Antibiotic use in human medicine and agriculture continually selects for resistant bacteria [2, 6]. For example, tetracycline and  $\beta$ -lactams commonly fed to animals provide a selective environment for tetracycline and methicillin resistance. Genes conferring resistance to these antibiotics have horizontally transferred into a sensitive human-associated *Staphylococcus aureus* strain, resulting in methicillin-resistant strain CC398 [7]. After a strain gains resistance by HGT, the bacteria proliferate and continue to evolve as they move among patients and hospitals [1]. This process occurs in many bacterial lineages, resulting in diverse populations of a variety of strains, such as USA300 [5].

### Transformation



### Conjugation



### Transduction



Figure 1. Mechanisms of bacterial horizontal gene transfer

## EXAMPLES IN CLINICAL MEDICINE

Ongoing HGT poses a problem for clinical surveillance and treatment. Bacterial populations evolve rapidly, resulting in diversity that necessitates individual screening to determine effective treatments and to detect new strains, such as methicillin and high level vancomycin resistant *S.aureus* (MRSA and VRSA) [2]. Even when new drugs and diagnostic tools become available, the persistence of HGT will require ongoing surveillance for newly resistant pathogens, leaving practitioners and researchers racing with evolution.

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## REFERENCES

1. Harris SR, Feil EJ, Holden MTG *et al.* Evolution of MRSA during hospital transmission and inter-continental spread. *Science* 2010;**327**:469–74.
2. Lindsay, J. A. Hospital-associated MRSA and antibiotic resistance—what have we learned from genomics? *Int J Med Microbiol* 2013;**303**:318–23
3. McCarthy AJ, Loeffler A, Witney AA *et al.* Extensive horizontal gene transfer during *Staphylococcus aureus* co-colonization in vivo. *Genome Biol Evol* 2014;**6**:2697–708.
4. Stanczak-Mrozek KI, Manne A, Knight GM *et al.* Within-host diversity of MRSA antimicrobial resistances. *J Antimicrob Chemother* 2015;**70**: 2191–2198.
5. McDougal LK, Steward CD, Killgore GE *et al.* Pulsed-field gel electrophoresis typing of oxacillin-resistant *Staphylococcus aureus* isolates

from the United States: establishing a national database. *J Clin Microbiol* 2003;**41**:5113–20.

6. US Department of Health and Human Services. *Antibiotic Resistance Threats in the United States*. Atlanta: CDC, 2013; p, 11–14.

7. Price LB, Stegger M, Hasman H *et al*. *Staphylococcus aureus* CC398: host adaptation and emergence of methicillin resistance in livestock. *MBio* 2012;**3**.