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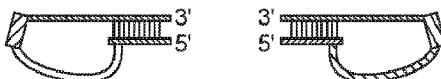
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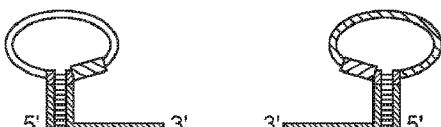
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(54) Title: NOVEL PRIMERS AND USES THEREOF

Scheme A: 3'-target-StemLoop

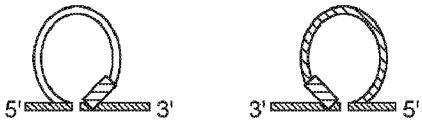


Scheme B: 5'-target-StemLoop



- 5'-universal adapter
- 3'-universal adapter
- Target-specific primer
- Degenerate nt
- StemLoop Forward Stem
- StemLoop Reverse Stem
- GC stabilizer

Scheme C: Split primer



Control Scheme: standard degenerate primer

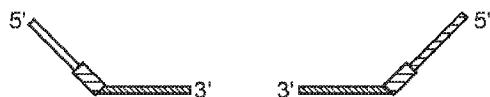


FIG. 1

(57) Abrégé/Abstract:

Disclosed here is a composition comprising a primer that is (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to

(57) Abrégé(suite)/Abstract(continued):

form a stem structure, or (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section. Also disclosed is a method for amplifying a target locus of interest from a template DNA, comprising at least two pre-amplification cycles using the loopable primer, the split primer and/or the split-loopable primer, wherein each amplification cycle comprises annealing the primer to the template DNA or pre-amplification product thereof and elongating the annealed primer. Further disclosed is a kit for amplifying a target locus of interest, comprising the loopable primer, the split primer, and/or the split-loopable primer.

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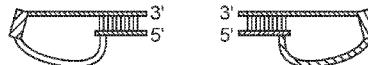
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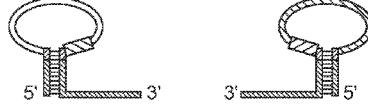
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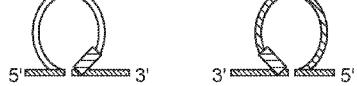
Scheme A: 3'-target-StemLoop



Scheme B: 5'-target-StemLoop



Scheme C: Split primer



- 5'-universal adapter
- 3'-universal adapter
- Target-specific primer
- Degenerate nt
- StemLoop Forward Stem
- StemLoop Reverse Stem
- GC stabilizer

Control Scheme: standard degenerate primer

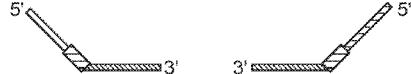


FIG. 1

(57) Abstract: Disclosed here is a composition comprising a primer that is (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section. Also disclosed is a method for amplifying a target locus of interest from a template DNA, comprising at least two pre-amplification cycles

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[Continued on next page]

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using the loopable primer, the split primer and/or the split-loopable primer, wherein each amplification cycle comprises annealing the primer to the template DNA or pre-amplification product thereof and elongating the annealed primer. Further disclosed is a kit for amplifying a target locus of interest, comprising the loopable primer, the split primer, and/or the split-loopable primer.

NOVEL PRIMERS AND USES THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/617,066, filed January 12, 2018, which is hereby incorporated by reference in its entirety.

SEQUENCE LISTING

[0002] The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. Said ASCII copy, created on December 27, 2018, is named N_022_WO_01_SL.txt and is 3,844 bytes in size.

BACKGROUND

[0003] Molecular barcodes or indexing sequences have been used in next generation sequencing to reduce quantitative bias introduced by replication, by tagging each nucleic acid fragment with a molecular barcode or indexing sequence. Sequence reads that have different molecular barcodes or indexing sequences represent different original nucleic acid molecules. By referencing the molecular barcodes or indexing sequences, PCR artifacts, such as sequence changes generated by polymerase errors that are not present in the original nucleic acid molecules can be identified and separated from real variants/mutations present in the original nucleic acid molecules.

[0004] However, in order to apply molecular barcodes or indexing sequences in highly multiplex PCR, a need exists for suppressing primer dimers formation, avoiding barcode resampling, and reducing nonspecific primer binding and formation of primer concatamers.

SUMMARY

[0005] The present inventions are directed to compositions, methods, and kits for

amplification of nucleic acids. In a first aspect, the inventions described herein relate to a composition comprising a primer that is: (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section.

[0006] In a second aspect, the inventions described herein relate to a method for amplifying a target locus of interest from a template DNA, comprising at least two pre-amplification cycles using a primer that is: (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section; wherein each pre-amplification cycle comprises annealing the primer to the template DNA or pre-amplification product thereof and elongating the annealed primer.

[0007] In a third aspect, the inventions described herein relate to a kit for amplifying a target locus of interest, comprising a primer that is: (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor

section positioned between the first target-specific section and the second target-specific section, or (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section.

[0008] In a fourth aspect, the inventions described herein relate to a method for determining copy number variation of a target locus of interest, comprising: pre-amplifying the target locus of interest from a template DNA using at least two pre-amplification cycles with: (a) one or more loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, (b) one or more split-loopable primers each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, a molecular indexing section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, or (c) one or more split-loopable primers each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, a molecular indexing section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule

indexing sequence; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and sequencing the amplification product to determine copy number variation of the target locus of interest using the molecule indexing sequence.

[0009] In a fifth aspect, the inventions described herein relate to a method for determining fetal aneuploidy, comprising: pre-amplifying a plurality of target loci of interest of one or more chromosomes from cell-free DNA isolated from a maternal blood sample, using at least two pre-amplification cycles with: (a) a plurality of loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, (b) a plurality of split-loopable primers each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, a molecular indexing section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, or (c) a plurality of split-loopable primers each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, a molecular indexing section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and

sequencing the amplification product to determine fetal aneuploidy using the molecule indexing sequence.

[0010] In a sixth aspect, the inventions described herein relate to a method for multiplex amplification, comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification; and wherein the first primer and the second primer comprise complementary sequences in their target-specific sections and are capable of forming a primer dimer absent protection by the stem-forming section; and amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence. The prevention of primer-dimer formation is particularly useful for PCR tiling (e.g., amplifying overlapping or tiled target sequences in a single multiplex PCR reaction).

[0011] In a seventh aspect, the inventions described herein relate to a method for allele-

specific amplification, comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the loopable primer comprises an SNV or SNP allele in the 5'- or 3'-portion of the target-specific section, (b) a split-loopable primer comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the split-loopable primer comprises an SNV or SNP allele in the target-specific section, or (c) a split-loopable primer comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the split-loopable primer comprises an SNV or SNP allele in the 3'-portion of the target-specific section; and amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence.

[0012] In an eighth aspect, the inventions described herein relate to a method for allele-specific quantitative PCR (qPCR), comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-

portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV

or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and detecting real-time intensity of fluorescent signal from the first fluorescent probe and the second fluorescent probe. Alternatively, the method for allele-specific qPCR does not require a pre-amplification step, and instead comprises amplifying one or more target loci of interest from a template DNA using the primer of (a), (b) or (c) in the presence of the first fluorescent probe and the second fluorescent probe; and detecting real-time intensity of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

[0013] In a ninth aspect, the inventions described herein relate to a method for allele-specific digital PCR (dPCR), comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first

fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele; partitioning the pre-amplification product into a plurality of reaction volumes; amplifying the pre-amplification product in each reaction volume using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and detecting presence or absence of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

Alternatively, the method for allele-specific dPCR does not require a pre-amplification step, and instead comprises partitioning a sample into a plurality of reaction volumes; amplifying one or more target loci of interest from a template DNA in each reaction volume using the primer of (a), (b) or (c) in the presence of the first fluorescent probe and the second fluorescent probe; and detecting presence or absence of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

[0014] These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction

with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 shows some embodiments of the primers described herein (Scheme A to C and Control Scheme).

[0016] FIG. 2 shows one embodiment of a loopable primer in which a 3'-end portion of the target-specific section is configured to form a stem structure with a complementary sequence.

[0017] FIG. 3 shows one embodiment of a loopable primer in which a 5'-end portion of the target-specific section is configured to form a stem structure with a complementary sequence.

[0018] FIG. 4 shows one embodiment of a split primer in which the target-specific section is split into a 5'-end portion and a 3'-end portion that are separated by an adaptor sequence.

[0019] FIG. 5 shows workflow of an example amplification process including 2 pre-amplification cycles using the primers described herein.

[0020] FIG. 6 shows on-target rates of the example amplification process including 2 pre-amplification cycles using the primers described herein.

[0021] FIG. 7 shows workflow of an example amplification process including 3 or 10 pre-amplification cycles using the primers described herein.

[0022] FIG. 8 shows on-target rates of the example amplification process including 3 or 10 pre-amplification cycles using the primers described herein.

[0023] FIG. 9 shows consistent MIT counts between replicate samples (Scheme A, 2 pre-amplification cycles).

[0024] FIG. 10 shows primer and product sequences according to one embodiment of a loopable primer, which includes 2 mismatched nt in the loopable primer.

[0025] FIG. 11 shows primer and product sequences according to one embodiment of a loopable primer.

[0026] FIG. 12 shows primer and product sequences according to one embodiment of a split primer.

[0027] FIG. 13 shows some embodiments of the split-loopable primers described herein (Scheme D to E).

[0028] FIG. 14 shows consistent MIT counts between replicate samples in highly multiplex PCR (Scheme A, 2 pre-amplification cycles, workflow as FIG. 5). The on-target rate of this example amplification process is 83%.

DETAILED DESCRIPTION

[0029] Reference will now be made in detail to some specific embodiments of the invention contemplated by the inventors for carrying out the invention. Certain examples of these specific embodiments are illustrated in the accompanying drawings. While the invention is described in conjunction with these specific embodiments, it will be understood that it is not intended to limit the invention to the described embodiments. On the contrary, it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

[0030] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. Particular example embodiments of the present invention may be implemented without some or all of these specific details.

[0031] Various techniques and mechanisms of the present invention will sometimes be described in singular form for clarity. However, it should be noted that some embodiments include multiple iterations of a technique or multiple instantiations of a mechanism unless noted otherwise.

[0032] The disclosure of the following patent applications are incorporated herein by reference: International patent application No. PCT/US2006/045281 titled “SYSTEM AND METHOD FOR CLEANING NOISY GENETIC DATA AND USING DATA TO MAKE PREDICTIONS”; International patent application No. PCT/US2008/003547 titled “SYSTEM AND METHOD FOR CLEANING NOISY GENETIC DATA AND DETERMINING

CHROMOSOME COPY NUMBER”; International patent application No. PCT/US2009/034506 titled “METHODS FOR CELL GENOTYPING”; International patent application No. PCT/US2009/045335 titled “METHODS FOR EMBRYO CHARACTERIZATION AND COMPARISON”; International patent application No. PCT/US2009/052730 titled “METHODS FOR ALLELE CALLING AND PLOIDY CALLING”; International patent application No. PCT/US2010/050824 titled “METHODS FOR NON-INVASIVE PRENATAL PLOIDY CALLING”; International patent application No. PCT/US2011/037018 titled “METHODS FOR NON-INVASIVE PRENATAL PLOIDY CALLING”; International patent application No. PCT/US2011/061506 titled “METHODS FOR NON-INVASIVE PRENATAL PLOIDY CALLING”; International patent application No. PCT/US2011/066938 titled “METHODS FOR NON-INVASIVE PRENATAL PATERNITY TESTING”; International patent application No. PCT/US2012/066339 titled “HIGHLY MULTIPLEX PCR METHODS AND COMPOSITIONS”; International patent application No. PCT/US2013/055205 titled “METHODS AND COMPOSITIONS FOR REDUCING GENETIC LIBRARY CONTAMINATION”; International patent application No. PCT/US2013/057924 titled “METHODS FOR INCREASING FETAL FRACTION IN MATERNAL BLOOD”; International patent application No. PCT/US2014/051926 titled “METHODS OF USING LOW FETAL FRACTION DETECTION”; International patent application No. PCT/US2014/057843 titled “PRENATAL DIAGNOSTIC RESTING STANDARDS”; International patent application No. PCT/US2015/026957 titled “DETECTING MUTATIONS AND PLOIDY IN CHROMOSOMAL SEGMENTS”; International patent application No. PCT/US2016/031686 titled “METHODS AND COMPOSITIONS FOR DETERMINING PLOIDY”; and U.S. patent application No. 15/372,279 titled “COMPOSITIONS AND METHODS FOR IDENTIFYING NUCLEIC ACID MOLECULES.”

[0033] Loopable Primer

[0034] Many embodiments of the invention described herein relate to a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, and wherein the target-specific section is hybridizable to a target sequence of a template DNA intended for amplification.

[0035] In some embodiments, the adaptor section is positioned between the target-specific section and the stem-forming section, wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section. The adaptor section can be, for example, positioned at 5' side of the target-specific section and 3' side of the stem-forming section. In some embodiments, the adaptor section comprises a universal adaptor sequence for PCR amplification and/or sequencing.

[0036] In some embodiments, the loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence. Molecular indexing sequences, molecular index tags (MIT), or unique identifier (UID) sequences, are described in Kinde et al., PNAS 108(23):9530-9535 (2011), as well as in U.S. patent application No. 15/372,279 titled "COMPOSITIONS AND METHODS FOR IDENTIFYING NUCLEIC ACID MOLECULES," each of which is incorporated herein by reference in its entirety. In some embodiments, the length of each molecular indexing sequence is about 1-20 bp, or about 2-15 bp, or about 3-10 bp, or about 4-8 bp. When both a forward loopable primer and a reverse loopable primer according to the invention described herein are used for amplifying a target locus of interests, the amplification product can include two molecular indexing sequences, the combination of which allows even more accurate molecular counting than the use of a single molecular indexing sequence. In one embodiment, the molecule indexing sequence on each loopable primer is a unique molecule indexing sequence. In another embodiment, the combination of molecule indexing sequences on each pair of loopable forward and reverse primers are unique.

[0037] The molecular indexing section can be, for example, positioned between the target-specific section and the adaptor section. The molecular indexing section can be, for example, positioned at 5' side of the target-specific section and 3' side of the adaptor section. In some embodiments, hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section and the molecular indexing section.

[0038] In some embodiments, the loopable primer described herein excludes primers in which the target-specific section does not form part of the stem structure.

[0039] Because the loopable primers described herein hides/protects the universal adaptor sequences and the molecular indexing sequences, as well as at least part of the target-specific sequences, the loopable primers are capable of significantly improving assay specificity by suppressing primer dimers and non-specific binding in highly multiplex PCR.

[0040] **Scheme A:** FIG. 2 shows one scheme of the loopable primer in which the target-specific section comprises a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure. When the 3'-portion of the target-specific section is protected in the stem structure, the 5'-portion of the target-specific section is available for initiating target hybridization.

[0041] In some embodiments, hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the adaptor section and the 5'-portion of the target-specific section. The stem loop is designed to protect the molecule indexing sequence and the adaptor sequence from spurious interactions. The stem in the 3'-end also prevents primers from non-target specific extension (i.e. primer dimers).

[0042] In some embodiments, the loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section. In some embodiments, the loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 3'-terminus to prevent A-tailing. Alternatively or additionally, the 5'-terminus of the loopable primer may comprise one or more mismatched nucleotides that are not hybridizable to the target-specific section. In some embodiments, the loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 5'-terminus.

[0043] As shown in FIG. 10, a preferred embodiment of the loopable primer according to Scheme A comprises, from 5' to 3', one or more mismatched nucleotides, a stem-forming section, an adaptor section, a molecular indexing section, and a target-specific section, wherein the stem-forming section is the reverse complement of the 3'-portion of the target-specific section.

[0044] In some embodiments, the size of the stem structure formed between the stem-forming section and the 3'-portion of the target-specific section is about 5-20 bp, or about 5-10 bp, or about 10-15 bp, or about 15-20 bp.

[0045] In some embodiments, the loopable primer according to Scheme A has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the 3'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above. In some embodiments, the preferred annealing temperature is 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less. In some embodiments, the melting temperature is 60°C or above, or 61°C or above, or 62°C or above, or 63°C or above, or 64°C or above, or 65°C or above, 66°C or above, or 67°C or above, or 68°C or above, or 69°C or above, or 70°C or above. In some embodiments, extreme annealing temperatures may be useful, such as 30°C to 80°C.

[0046] **Scheme B:** FIG. 3 shows another scheme of the loopable primer in which the target-specific section comprises a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 5'-portion of the target-specific section to form a stem structure. When the 5'-portion of the target-specific section is protected in the stem structure, the 3'-portion of the target-specific section is available for initiating target hybridization

[0047] In some embodiments, hybridization between the stem-forming section and the 5'-portion of the target-specific section forms a loop that comprises the adaptor section but not the 3'-end portion of the target-specific section. The stem loop is designed to protect the molecule indexing sequence and the adaptor sequence from spurious interactions.

[0048] In some embodiments, the loopable primer further comprises one or more of G/C nucleotides positioned at the 5'-side of the target-specific section for stabilizing the stem structure with one or more complementary G/C nucleotides positioned at the 3'-side of the stem-forming section. In some embodiments, the loopable primer comprises 1, 2, 3, 4, or 5 G/C nucleotides positioned at the 5'-side of the target-specific section (i.e., at the neck of the stem loop).

[0049] As shown in FIG. 11, a preferred embodiment of the loopable primer according to Scheme B comprises, from 5' to 3', a stem-forming section, one or more G/C nucleotides, an adaptor section, a molecular indexing section, one or more G/C nucleotides, and a target-specific section, wherein the stem-forming section is the reverse complement of the 5'-portion of the target-specific section.

[0050] In some embodiments, the size of the stem structure formed between the stem-forming section and the 5'-portion of the target-specific section is about 5-20 bp, or about 5-10 bp, or about 10-15 bp, or about 15-20 bp.

[0051] In some embodiments, the loopable primer according to Scheme B has a preferred annealing temperature and a melting temperature for PCR reaction, wherein the stem-forming section and the 5'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above. In some embodiments, the preferred annealing temperature is 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less. In some embodiments, the melting temperature is 60°C or above, or 61°C or above, or 62°C or above, or 63°C or above, or 64°C or above, or 65°C or above, 66°C or above, or 67°C or above, or 68°C or above, or 69°C or above, or 70°C or above. In some embodiments, extreme annealing temperatures may be useful, such as 30°C to 80°C.

[0052] Split primer

[0053] Many embodiments of the invention described herein relate to a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, and wherein the target-specific section is hybridizable to a target sequence of a template DNA intended for amplification.

[0054] In some embodiments, the split primer further comprises a molecular indexing section comprising a molecule indexing sequence. The molecular indexing section can be, for example, positioned between the adaptor section and one of the target-specific sections. The molecular

indexing section can be, for example, positioned at 3' side of the adaptor section. In some embodiments, the length of each molecular indexing sequence is about 1-20 bp, or about 2-15 bp, or about 3-10 bp, or about 4-8 bp. When both a forward split primer and a reverse split primer according to the invention described herein are used for amplifying a target locus of interests, the amplification product can include two molecular indexing sequences, the combination of which allows even more accurate molecular counting than the use of a single molecular indexing sequence. In one embodiment, the molecule indexing sequence on each split primer is a unique molecule indexing sequence. In another embodiment, the combination of molecule indexing sequences on each pair of split forward and reverse primers are unique.

[0055] In some embodiments, the adaptor section comprises a universal adaptor sequence for PCR amplification and/or sequencing.

[0056] **Scheme C:** FIG. 4 shows one scheme of the split primer in which an adaptor section positioned between a first target-specific section and a second target-specific section. Both the first target-specific section and the second target-specific section are available for hybridization to target sequences.

[0057] In other words, the target-specific section is split into two parts and the universal adaptor sequence is placed in between. The molecular indexing sequences and adaptor sequences are protected after both ends of primers bind to target sequences. The split primer can be advantageous in terms of reducing sequencing distance.

[0058] As shown in FIG. 12, a preferred embodiment of the split primer according to Scheme C comprises, from 5' to 3', first target-specific section, an adaptor section, a molecular indexing section, second target-specific section.

[0059] Split-Loopable Primer

[0060] Many embodiments of the invention described herein relate to a split-loopable primer (a) comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or (b) comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section,

and a target-specific section; and wherein the (first and/or second) target-specific section is hybridizable to a target sequence of a template DNA intended for amplification.

[0061] In some embodiments, the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence. The molecular indexing section can be, for example, positioned between the adaptor section and the (second) target-specific sections. The molecular indexing section can be, for example, positioned at 3' side of the (second) adaptor section. In some embodiments, the length of each molecular indexing sequence is about 1-20 bp, or about 2-15 bp, or about 3-10 bp, or about 4-8 bp. When both a forward split-loopable primer and a reverse split-loopable primer according to the invention described herein are used for amplifying a target locus of interests, the amplification product can include two molecular indexing sequences, the combination of which allows even more accurate molecular counting than the use of a single molecular indexing sequence. In one embodiment, the molecule indexing sequence on each split-loopable primer is a unique molecule indexing sequence. In another embodiment, the combination of molecule indexing sequences on each pair of split-loopable forward and reverse primers are unique.

[0062] In some embodiments, the (first and/or second) adaptor section comprises a universal adaptor sequence for PCR amplification and/or sequencing.

[0063] **Scheme D:** FIG. 13 shows one scheme of the split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to the second target-specific section to form a stem structure. When the second target-specific section is protected in the stem structure, the first target-specific section is available for initiating target hybridization.

[0064] In some embodiments, hybridization between the stem-forming section and the second target-specific section forms a loop that comprises the adaptor section and the molecule indexing sequence. The stem loop is designed to protect the molecule indexing sequence and the adaptor sequence from spurious interactions. The stem in the 3'-end also prevents primers from non-target specific extension (i.e. primer dimers).

[0065] In some embodiments, the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the second target-specific section that are not hybridizable to the stem-forming section. In some embodiments, the split-loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 3'-terminus to prevent A-tailing. Alternatively or additionally, the 5'-end of the stem-forming section may comprise one or more mismatched nucleotides that are not hybridizable to the second target-specific section. In some embodiments, the split-loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 5'-end of the stem-forming section.

[0066] As shown in FIG. 13, a preferred embodiment of the split-loopable primer according to Scheme D comprises, from 5' to 3', first target-specific section, one or more mismatched nucleotides, a stem-forming section, an adaptor section, a molecular indexing section, and second target-specific section, wherein the stem-forming section is the reverse complement of part of the second target-specific section.

[0067] In some embodiments, the size of the stem structure formed between the stem-forming section and the second target-specific section is about 5-20 bp, or about 5-10 bp, or about 10-15 bp, or about 15-20 bp.

[0068] In some embodiments, the first target-specific section is longer than the second target-specific section. In some embodiments, the second target-specific section is longer than the first target-specific section.

[0069] In some embodiments, at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90% of the second target-specific section is hybridizable to the stem-forming region and capable of forming a stem.

[0070] In some embodiments, the split-loopable primer according to Scheme D has a preferred annealing temperature and a melting temperature for PCR reaction, wherein the stem-forming section and the second target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above. In some embodiments, the preferred annealing temperature is 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or

52°C or less, or 51°C or less, or 50°C or less. In some embodiments, the melting temperature is 60°C or above, or 61°C or above, or 62°C or above, or 63°C or above, or 64°C or above, or 65°C or above, 66°C or above, or 67°C or above, or 68°C or above, or 69°C or above, or 70°C or above. In some embodiments, extreme annealing temperatures may be useful, such as 30°C to 80°C.

[0071] **Scheme E:** FIG. 13 shows another scheme of the split-loopable primer comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section comprising a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure. When the 3'-portion of the target-specific section is protected in the stem structure, the 5'-portion of the target-specific section is available for initiating target hybridization.

[0072] In some embodiments, hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the second adaptor section, the molecule indexing sequence, and the 5'-portion of the target-specific section. The stem loop is designed to protect the molecule indexing sequence and the second adaptor sequence from spurious interactions. The stem in the 3'-end also prevents primers from non-target specific extension (i.e. primer dimers).

[0073] In some embodiments, the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section. In some embodiments, the split-loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 3'-terminus to prevent A-tailing. Alternatively or additionally, the 5'-end of the stem-forming section may comprise one or more mismatched nucleotides that are not hybridizable to the target-specific section. In some embodiments, the split-loopable primer comprises 1, 2, 3, 4, or 5 mismatched nucleotides at 5'-end of the stem-forming section

[0074] As shown in FIG. 13, a preferred embodiment of the split-loopable primer according to Scheme E comprises, from 5' to 3', first adaptor section, one or more mismatched nucleotides, a stem-forming section, second adaptor section, a molecular indexing section, and a target-

specific section, wherein the stem-forming section is the reverse complement of the 3'-portion of the target-specific section.

[0075] In some embodiments, the size of the stem structure formed between the stem-forming section and the 3'-portion of the target-specific section is about 5-20 bp, or about 5-10 bp, or about 10-15 bp, or about 15-20 bp.

[0076] In some embodiments, the first adaptor section is longer than the second adaptor section. In some embodiments, the second adaptor section is longer than the first adaptor section.

[0077] In some embodiments, the split-loopable primer according to Scheme E has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the 3'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above. In some embodiments, the preferred annealing temperature is 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less. In some embodiments, the melting temperature is 60°C or above, or 61°C or above, or 62°C or above, or 63°C or above, or 64°C or above, or 65°C or above, 66°C or above, or 67°C or above, or 68°C or above, or 69°C or above, or 70°C or above. In some embodiments, extreme annealing temperatures may be useful, such as 30°C to 80°C.

[0078] Primer Composition

[0079] Further embodiments of the invention described herein relate to a primer composition comprising the loopable primers, split primers, and/or split-loopable primers described herein.

[0080] In some embodiments, the primer composition comprises at least a forward loopable primer and a reverse loopable primer that target the same locus of interest for amplification. In some embodiments, both the forward loopable primer and the reverse loopable primer correspond to Scheme A shown in FIG. 2. In some embodiments, both the forward loopable primer and the reverse loopable primer correspond to Scheme B shown in FIG. 3.

[0081] In some embodiments, the primer composition comprises at least a forward split primer and a reverse split primer that target the same locus of interest for amplification. In some embodiments, both the forward split primer and the reverse loopable split correspond to Scheme C shown in FIG. 3.

[0082] In some embodiments, the primer composition comprises at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification. In some embodiments, both the forward split-loopable primer and the reverse split-loopable primer correspond to Scheme E shown in FIG. 13. In some embodiments, both the forward split-loopable primer and the reverse split-loopable primer correspond to Scheme E shown in FIG. 13.

[0083] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different loopable primers. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse loopable primers.

[0084] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different loopable primers each comprising a different stem-forming section. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different loopable primers each comprising a different molecular indexing sequence. In some embodiments, the composition comprises at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 different loopable primers each comprising a different combination of the stem-forming section and the molecular indexing sequence.

[0085] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split primers. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse split primers.

[0086] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split primers each comprising a different target-specific section. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split primers each comprising a different molecular indexing sequence. In some embodiments, the composition comprises at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 different split primers each comprising a different combination of the target-specific section and the molecular indexing sequence.

[0087] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split-loopable primers. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse split-loopable primers.

[0088] In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split-loopable primers each comprising a different stem-forming section. In some embodiments, the composition comprises at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split-loopable primers each comprising a different molecular indexing sequence. In some embodiments, the composition comprises at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 different split-loopable primers each comprising a different combination of the stem-forming section and the molecular indexing sequence.

[0089] Methods for Amplification of Nucleic Acids

[0090] Further embodiments of the invention described herein relate to a method for amplifying a target locus of interest from a template DNA, comprising at least two pre-amplification cycles using the loopable primer described above or the split primer described above or the split-loopable primer described above, wherein each pre-amplification cycle

comprises annealing the primer to the template DNA or pre-amplification product thereof and elongating the annealed primer.

[0091] In some embodiments, the method comprises at least three, at least four, at least five, at least ten, or up to fifteen, or up to ten, or up to seven, or up to five pre-amplification cycles.

[0092] In some embodiments, each pre-amplification cycle comprises annealing at least a forward loopable primer and a reverse loopable primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward loopable primer and the annealed reverse loopable primer. In some embodiments, both the forward loopable primer and the reverse loopable primer correspond to Scheme A shown in FIG. 2. In some embodiments, both the forward loopable primer and the reverse loopable primer correspond to Scheme B shown in FIG. 3.

[0093] In some embodiments, each pre-amplification cycle comprises annealing at least a forward split primer and a reverse split primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward split primer and the annealed reverse split primer. In some embodiments, both the forward loopable primer and the reverse loopable primer correspond to Scheme C shown in FIG. 4.

[0094] In some embodiments, each pre-amplification cycle comprises annealing at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward split-loopable primer and the annealed reverse split-loopable primer. In some embodiments, both the forward split-loopable primer and the reverse split-loopable primer correspond to Scheme D shown in FIG. 13. In some embodiments, both the forward split-loopable primer and the reverse split-loopable primer correspond to Scheme E shown in FIG. 13.

[0095] As shown in FIG. 10, when a pair of forward and reverse loopable primers according to Scheme A are used, the pre-amplification product can comprise, for example, from 5' to 3', one or more mismatched nucleotides, first stem-forming section, first adaptor section, first molecular indexing section, amplified target sequences, second molecular indexing section, second adaptor section, second stem-forming section, and one or more mismatched nucleotides.

[0096] As shown in FIG. 11, when a pair of forward and reverse loopable primers according to Scheme B are used, the pre-amplification product can comprise, for example, from 5' to 3', first stem-forming section, one or more G/C nucleotides, first adaptor section, first molecular indexing section, amplified target sequences, second molecular indexing section, second adaptor section, one or more G/C nucleotides, and second stem-forming section.

[0097] As shown in FIG. 12, when a pair of forward and reverse split primers according to Scheme C are used, the pre-amplification product can comprise, for example, from 5' to 3', 5'-target-specific sequences, first adaptor section, first molecular indexing section, amplified target sequences, second molecular indexing section, second adaptor section, and 3'-target-specific sequences.

[0098] In some embodiments, the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the method further comprises a plurality of PCR cycles using one or more PCR primers hybridizable to the universal adaptor sequence.

[0099] In some embodiments, the PCR primer comprises a sequencing adaptor for downstream high-throughput sequencing of the PCR products. In some embodiments, the PCR primer comprises a sample barcode for pooling of the PCR products for further analysis.

[0100] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different loopable primers each comprising a different stem-forming section, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different loopable primers each comprising a different molecular indexing sequence, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 different loopable primers each comprising a different combination of the stem-forming section and the molecular indexing sequence, to the template DNA or pre-amplification product thereof.

[0101] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse loopable primers to the template DNA or pre-amplification product thereof.

[0102] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split primers each comprising a different target-specific section, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split primers each comprising a different molecular indexing sequence, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 split primers each comprising a different combination of the target-specific section and the molecular indexing sequence, to the template DNA or pre-amplification product thereof.

[0103] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse split primers to the template DNA or pre-amplification product thereof.

[0104] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split-loopable primers each comprising a different stem-forming section, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different split-loopable primers each comprising a different molecular indexing sequence, to the template DNA or pre-amplification product thereof. In some embodiments, each pre-amplification cycle comprises annealing at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, at least 10,000, at least 20,000, at least 50,000, or at least 100,000 different split-loopable primers each comprising a different

combination of the stem-forming section and the molecular indexing sequence, to the template DNA or pre-amplification product thereof.

[0105] In some embodiments, each pre-amplification cycle comprises annealing at least 50, at least 100, at least 200, at least 500, at least 1,000, at least 2,000, at least 5,000, or at least 10,000 different pairs of forward and reverse split-loopable primers to the template DNA or pre-amplification product thereof.

[0106] In some embodiments, the loopable primer according to Scheme A has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the 3'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above, and wherein the annealing temperature for the pre-amplification cycles is at or below the preferred annealing temperature (e.g., 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less).

[0107] In some embodiments, the loopable primer according to Scheme B has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the 5'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above, and wherein the annealing temperature for the pre-amplification cycles is at or below the preferred annealing temperature (e.g., 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less).

[0108] In some embodiments, the split-loopable primer according to Scheme D has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the second target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above, and wherein the annealing temperature for the pre-amplification cycles is at or below the preferred annealing temperature (e.g., 60°C or less, 59°C or less, or 58°C or less, or 57°C or

less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less).

[0109] In some embodiments, the split-loopable primer according to Scheme E has a preferred annealing temperature for PCR reaction and a melting temperature, wherein the stem-forming section and the 5'-portion of the target-specific section form the stem structure at the preferred annealing temperature or below and do not form the stem structure at the melting temperature or above, and wherein the annealing temperature for the pre-amplification cycles is at or below the preferred annealing temperature (e.g., 60°C or less, 59°C or less, or 58°C or less, or 57°C or less, or 56°C or less, or 55°C or less, 54°C or less, or 53°C or less, or 52°C or less, or 51°C or less, or 50°C or less).

[0110] In other embodiments, the annealing temperature for the pre-amplification cycles can be below 50°C, or below 40°C, or below 30°C, or below 20°C, or above 60°C, or above 65°C, or above 70°C. In other embodiments, extreme annealing temperatures may be useful for the pre-amplification cycles, such as 30°C to 80°C.

[0111] Kits for Amplification of Nucleic Acids

[0112] Further embodiments of the invention described herein relate to a kit for amplifying a target locus of interest from a template DNA, comprising a loopable primer described above or a split primer described above or a split-loopable primer described above.

[0113] In some embodiments, the kit comprises at least a forward loopable primer and a reverse loopable primer that target the same locus of interest for amplification. In some embodiments, the kit comprises at least a forward split primer and a reverse split primer that target the same locus of interest for amplification. In some embodiments, the kit comprises at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification.

[0114] In some embodiments, the kit further comprises a polymerase for elongating the loopable primer or the split primer or the split-loopable primer during the pre-amplification cycles.

[0115] In some embodiments, the kit further comprises a protease for inactivating the aforementioned polymerase upon completion of the pre-amplification cycles.

[0116] In some embodiments, the kit further comprises one or more PCR primers hybridizable to the universal adaptor sequence in the adaptor section of the loopable primer or the split primer or the split-loopable primer. In some embodiments, the PCR primer comprises a sequencing adaptor for downstream high-throughput sequencing of the PCR products. In some embodiments, the PCR primer comprises a sample barcode for pooling of the PCR products for further analysis.

[0117] Applications

[0118] The loopable primer of Scheme A (3'-target-StemLoop) that hides/protects the universal adapter sequences and the MIT sequences improves assay specificity by suppressing primer dimers and non-specific binding in high multiplex PCR. Accordingly, the loopable primer of Scheme A is particularly useful for the following applications:

[0119] Copy number variant detection (CNV, aneuploidies, microdeletions, etc): With each DNA fragments product attached to a unique (or a unique combination) of molecular index tags, it allows tracking of the number of fragments in a sample of a specific locus (sequence of amplicon).

[0120] PCR-error removal, real mutation detection: By using MIT barcodes, PCR artifacts, such as sequence changes generated by polymerase errors that are not present in the original molecules can be identified and separated from the real variants/mutations present in the original molecules.

[0121] PCR tiling: The stem in the 3'-end of the primers prevent primer dimer formation, which can be very useful for amplifying overlapping or tiled amplicons in a single multiplex PCR reaction.

[0122] Allele-specific amplification: Allele specific primers with the mutant base position placed in the stem region (3'-end of primer) will inhibit the stem from opening with the mismatch wild type and thereby prevent amplification of the wild type.

[0123] Mutant allele specific quantitative PCR (qPCR) and digital PCR (qPCR): Primers for mutation and wild type have different tag sequences that can be detected by different fluorescent probes colors and other detection methods.

[0124] Additional embodiments of the invention described herein relate to a method for determining copy number variation of a target locus of interest, comprising: pre-amplifying the target locus of interest from a template DNA using at least two pre-amplification cycles with one or more loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and sequencing the amplification product to determine copy number variation of the target locus of interest using the molecule indexing sequence.

[0125] Additional embodiments of the invention described herein relate to a method for determining fetal aneuploidy, comprising: pre-amplifying a plurality of target loci of interest of one or more chromosomes from cell-free DNA isolated from a maternal blood sample, using at least two pre-amplification cycles with a plurality of loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and sequencing the amplification product to determine fetal aneuploidy using the molecule indexing sequence.

[0126] Additional embodiments of the invention described herein relate to a method for multiplex amplification, comprising: pre-amplifying one or more target loci of interest from a

template DNA using at least two pre-amplification cycles with at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the first loopable primer and the second loopable primer comprise complementary sequences in their target-specific sections and are capable of forming a primer dimer absent protection by the stem-forming section; and amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence.

[0127] Additional embodiments of the invention described herein relate to a method for allele-specific amplification, comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the loopable primer comprises an SNV or SNP allele in the 5'- or 3'-portion of the target-specific section; and amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence.

[0128] Additional embodiments of the invention described herein relate to a method for allele-specific quantitative PCR (qPCR), comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the

target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele; amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and detecting real-time intensity of fluorescent signal from the first fluorescent probe and the second fluorescent probe. Alternatively, the method for allele-specific qPCR does not require a pre-amplification step, and instead comprises amplifying one or more target loci of interest from a template DNA using the first and second loopable primers in the presence of the first and second fluorescent probes; and detecting real-time intensity of fluorescent signal from the first and second fluorescent probes.

[0129] Additional embodiments of the invention described herein relate to a method for allele-specific digital PCR (dPCR), comprising: pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele; partitioning the pre-amplification product into a plurality of reaction volumes; amplifying the pre-amplification product in each reaction volume using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and detecting presence or absence of fluorescent signal from the first fluorescent probe and the second fluorescent probe. Alternatively, the method for allele-specific dPCR does not require a pre-amplification step, and instead comprises partitioning a sample into a plurality of reaction volumes; amplifying one or more target loci of interest from a template DNA in each reaction volume using the first and second loopable primers in the presence of the first and second

fluorescent probes; and detecting presence or absence of fluorescent signal from the first and second fluorescent probes.

[0130] WORKING EXAMPLES

[0131] Example 1: 2-Cycle Workflow

[0132] A proof-of-concept experiment was conducted to amplify sample DNA using the 2-cycle workflow as shown in FIG. 5. For each combination of primer scheme (FIG. 1), commercially available high fidelity enzyme mixes and DNA was prepared.

Master Mix	initial		vol [ul]	final	
1.6X Enzyme Mix	1.6	X	6.25	1	X
4X Primer Mix	4	X	2.5	1	X
DNA			1.25	1	X
Final			10		

*same formulation for all polymerase tested.

[0133] MIT by Direct-PCR Reactions: Samples were cycled at the following conditions. After 2 cycles, 20 μ L of prepared Protease solution was added to the reaction and incubated at 65° C for 15 minutes, followed by a 15 minute inactivation at 95° C.

Primers	DNA input [ng]	Primer Conc. [nM]	Annealing Time [min]	Annealing Temp [C]	PCR cycles*	Polymerase Condition
MIT_F+MIT_R	15 ng	20 nM	6 min	50° C	2	3 commercially available enzymes

Step	# of Cycles	Temperature	Time		
Denaturation	1	98° C	30 seconds		
Cycle	2, 3 or 10	98° C	10 seconds		
		50° C	6 minutes		
		72° C	30 seconds		
Add Protease	1	65° C	15 minutes	heating block in the hood	
Inactivation	1	95° C	15 minutes		
Hold	1	4° C	Infinite		

[0134] Sequencing Barcoding Reactions: 10 μ L of the 30 μ L resultant volume was taken into a Q5 barcoding reaction and cycled 35 times to full plateau.

reagent	Stock		Volume [μ L]	Final	
2x Q5 Master Mix	2 x		20.0	1 x	
Universal FBC primer	10 μ M		1.6	0.4 μ M	
Reverse RBC primer	5 μ M		3.2	0.4 μ M	
Nuclease-free water			5.2		
Barcoded DNA (30 μ L in total)			10		
Total volume			40		

Step	# of Cycles	Temperature	Time	
Hold	1	98°C	3 minutes	
Cycle	35	98°C	30 seconds	
		62.5°C	30 seconds	MAX mode
		72°C	30 seconds	
Hold	1	72°C	2 minutes	
Hold	1	4°C	Infinite	

[0135] Pooling and Purification: 2 μ L of each sample were pooled together and 50 μ L of Pool was purified using Qiagen Qiaquick spin column.

Transfer 2 μ L from each row of BAR plate(s) to strip tube. Cap and spin.		
Transfer contents into POOL_MIX1 tube		
Vortex POOL_MIX1 tubes for 10 pulses of 2 seconds, quick spin for 5-10 seconds		
Transfer 50 μ L of POOL_MIX1 to the new POOL_MIX2 tube.		
Discard POOL_MIX1 tubes, adhesive seal and freeze the ~BAR plate(s).		
Add 250 μ L Qiagen PB Buffer.		
Add 5 μ L 3M NaOAc.		
Vortex for 10 pulses for 2 seconds and quick spin. Check that the color is yellow.		
Pipette pool into column. There should be 305 μ L of Pool.		
Spin 14,000 x g for 1 minute.		
Discard flow-through and collection tube. Replace with a new collection tube.		
Add 700 μ L Qiagen PE buffer(make sure EtOH was added).		
Spin at about 14,000 x g for 1 minute.		
Discard flow-through and collection tube. Replace with a new collection tube.		
Spin at about 14,000 x g for 2 minute. Discard flow-through and collection tube.		
Place column in the corresponding -POOL tube.		
Add 100 μ L Qiagen EB(elution buffer).		
Close cap and incubate at room temperature for 3 minutes.		
Spin at about 14,000 x g for 1 minute.		
If any residual elution buffer above column, pipette it to column and re-spin.		
Discard column.		

[0136] Sample was quantified by qPCR and sequenced.

[0137] As shown in FIG. 6, each of Scheme A, Scheme B, and Scheme C was able to amplify the target locus of interest with 2 pre-amplification cycles (followed by downstream PCR amplification using primers hybridizable to the universal adaptor sequence), with scheme A showing the best on-target rate. As shown in FIG. 9, MIT counts were very consistent between replicate samples (Scheme A, 2 pre-amplification cycles).

[0138] Example 2: 3/10-Cycle Workflow

[0139] A proof-of-concept experiment was conducted to amplify sample DNA using the 3-cycle or 10-cycle workflow as shown in FIG. 7. For each combination of primer scheme (see FIG. 1), commercially available high fidelity enzyme mixes and DNA was prepared.

Master Mix	initial		vol [ul]	final	
1.6X Enzyme Mix	1.6	X	6.25	1	X

4X Primer Mix	4	X	2.5	1	X
DNA			1.25	1	X
Final			10		

*same formulation for all polymerase tested.

[0140] MIT by Direct-PCR Reactions: Samples were cycled at the following conditions.

After 3 or 10 cycles, 20 μ L of prepared Protease solution was added to the reaction and incubated at 65° C for 15 minutes, followed by a 15 minute inactivation at 95° C.

Primers	DNA input [ng]	Primer Conc. [nM]	Annealing Time [min]	Annealing Temp [C]	PCR cycles*	Polymerase Condition
MIT_F+MIT_R	15 ng	20 nM	6 min	50° C	3 10	3 commercially available enzymes

Step	# of Cycles	Temperature	Time			
Denaturation	1	98° C	30 seconds			
Cycle	2, 3 or 10	98° C	10 seconds			
		50° C	6 minutes			
		72° C	30 seconds			
Add Protease	1	65° C	15 minutes	heating block in the hood		
Inactivation	1	95° C	15 minutes			
Hold	1	4° C	Infinite			

[0141] Sequencing Barcoding Reactions: 10 μ L of the 30 μ L resultant volume was taken into a Q5 barcoding reaction and cycled 35 times to full plateau.

reagent	Stock		Volume [uL]	Final	
2x Q5 Master Mix	2	x	20.0	1	x
Universal FBC primer	10	uM	1.6	0.4	uM
Reverse RBC primer	5	uM	3.2	0.4	uM
Nuclease-free water			5.2		
Barcode DNA (30uL in total)			10		
Total volume			40		

Step	# of Cycles	Temperature	Time	
Hold	1	98°C	3 minutes	
Cycle	35	98°C	30 seconds	
		62.5°C	30 seconds	MAX mode
		72°C	30 seconds	
Hold	1	72°C	2 minutes	
Hold	1	4°C	Infinite	

[0142] Pooling and Purification: 2 µL of each sample were pooled together and 50 µL of Pool was purified using Qiagen Qiaquick spin column.

Transfer 2 μ L from each row of BAR plate(s) to strip tube. Cap and spin.		
Transfer contents into POOL_MIX1 tube		
Vortex POOL_MIX1 tubes for 10 pulses of 2 seconds, quick spin for 5-10 seconds		
Transfer 50 μ L of POOL_MIX1 to the new POOL_MIX2 tube.		
Discard POOL_MIX1 tubes, adhesive seal and freeze the ~BAR plate(s).		
Add 250 μ L Qiagen PB Buffer.		
Add 5 μ L 3M NaOAc.		
Vortex for 10 pulses for 2 seconds and quick spin. Check that the color is yellow.		
Pipette pool into column. There should be 305 μ L of Pool.		
Spin 14,000 x g for 1 minute.		
Discard flow-through and collection tube. Replace with a new collection tube.		
Add 700 μ L Qiagen PE buffer(make sure EtOH was added).		
Spin at about 14,000 x g for 1 minute.		
Discard flow-through and collection tube. Replace with a new collection tube.		
Spin at about 14,000 x g for 2 minute. Discard flow-through and collection tube.		
Place column in the corresponding -POOL tube.		
Add 100 μ L Qiagen EB(elution buffer).		
Close cap and incubate at room temperature for 3 minutes.		
Spin at about 14,000 x g for 1 minute.		
If any residual elution buffer above column, pipette it to column and re-spin.		
Discard column.		

[0143] Sample was quantified by qPCR and sequenced.

[0144] As shown in FIG. 8, each of Scheme A, Scheme B, and Scheme C was able to amplify the target locus of interest with 3 or 10 pre-amplification cycles (followed by downstream PCR amplification using primers hybridizable to the universal adaptor sequence), with scheme A showing the best on-target rate at 3 pre-amplification cycles and scheme C showing the best on-target rate at 10 pre-amplification cycles.

[0145] In the foregoing description, it will be readily apparent to one skilled in the art that varying substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention. The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations, which is not specifically disclosed herein. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of

the invention. Thus, it should be understood that although the present invention has been illustrated by specific embodiments and optional features, modification and/or variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scopes of this invention.

CLAIMS

What is claimed is:

1. A composition comprising a primer that is:
 - (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or
 - (b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or
 - (c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section.
2. The composition of claim 1, wherein the primer is a loopable primer.
3. The composition of claim 2, wherein the adaptor section is positioned between the target-specific section and the stem-forming section, and wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section.
4. The composition of claim 3, wherein the adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.
5. The composition of claim 2, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.
6. The composition of claim 5, wherein the molecular indexing section is positioned between the target-specific section and the adaptor section.
7. The composition of claim 6, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the adaptor section, and wherein

hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section and the molecular indexing section.

8. The composition of claim 2, wherein the target-specific section comprises a 5'-portion and a 3'-portion, and wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section.

9. The composition of claim 8, wherein hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the adaptor section and the 5'-portion of the target-specific section.

10. The composition of claim 8, wherein the loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

11. The composition of claim 2, wherein the target-specific section comprises a 5'-portion and a 3'-portion, and wherein the stem-forming section is hybridizable to a 5'-portion of the target-specific section.

12. The composition of claim 11, wherein hybridization between the stem-forming section and the 5'-portion of the target-specific section forms a loop that comprises the adaptor section but not the 3'-end portion of the target-specific section.

13. The composition of claim 11, wherein the loopable primer further comprises one or more of G or C nucleotides positioned at the 5'-side of the target-specific section for stabilizing the stem structure with one or more complementary G or C nucleotides optionally positioned at the 3'-side of the stem-forming section.

14. The composition of claim 2, comprising at least a forward loopable primer and a reverse loopable primer that target the same locus of interest for amplification.

15. The composition of claim 1, wherein the primer is a split primer.

16. The composition of claim 15, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.

17. The composition of claim 16, wherein the molecular indexing section is positioned between the adaptor section and one of the target-specific section.

18. The composition of claim 17, wherein the molecular indexing section is positioned at 3' side of the adaptor section.

19. The composition of claim 15, comprising at least a forward split primer and a reverse split primer that target the same locus of interest for amplification.

20. The composition of claim 1, wherein the primer is a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section.

21. The composition of claim 20, wherein the adaptor section is positioned between the stem-forming section and the second target-specific section, wherein hybridization between the stem-forming section and a portion of the second target-specific section forms a loop that comprises the adaptor section.

22. The composition of claim 21, wherein the adaptor section is positioned at 5' side of the second target-specific section and 3' side of the stem-forming section.

23. The composition of claim 22, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the second target-specific section that are not hybridizable to the stem-forming section.

24. The composition of claim 20, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

25. The composition of claim 24, wherein the molecular indexing section is positioned between the adaptor section and the second target-specific section.

26. The composition of claim 25, wherein the molecular indexing section is positioned at 5' side of the second target-specific section and 3' side of the adaptor section, and wherein hybridization between the stem-forming section and a portion of the second target-

specific section forms a loop that comprises the adaptor section and the molecular indexing section.

27. The composition of claim 20, comprising at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification.

28. The composition of claim 1, wherein the primer is a split-loopable primer comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section.

29. The composition of claim 28, wherein the second adaptor section is positioned between the stem-forming section and the target-specific section, wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section.

30. The composition of claim 29, wherein the second adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.

31. The composition of claim 28, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

32. The composition of claim 31, wherein the molecular indexing section is positioned between the second adaptor section and the target-specific section.

33. The composition of claim 32, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the second adaptor section, and wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section and the molecular indexing section.

34. The composition of claim 28, wherein the target-specific section comprises a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section, and wherein hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the second adaptor section

and the 5'-portion of the target-specific section.

35. The composition of claim 34, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

36. The composition of claim 28, comprising at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification.

37. The composition of claim 1, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification and/or sequencing.

38. The composition of claim 1, comprising at least 50 different primers each comprising a different stem-forming section.

39. The composition of claim 1, comprising at least 50 different primers each comprising a different molecular indexing sequence.

40. The composition of claim 1, comprising at least 2,500 different primers each comprising a different combination of the stem-forming section and the molecular indexing sequence.

41. A method for amplifying a target locus of interest from a template DNA, comprising at least two pre-amplification cycles using a primer that is:

(a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or

(b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or

(c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second

adaptor section;

wherein each pre-amplification cycle comprises annealing the primer to the template DNA or pre-amplification product thereof and elongating the annealed primer.

42. The method of claim 41, wherein the method comprises three or more pre-amplification cycles using the loopable primer or the split primer or the split-loopable primer.

43. The method of claim 41, wherein the method comprises five or more pre-amplification cycles using the loopable primer or the split primer or the split-loopable primer.

44. The method of claim 41, wherein the method comprises ten or fewer pre-amplification cycles using the loopable primer or the split primer or the split-loopable primer.

45. The method of claim 41, wherein the primer is a loopable primer.

46. The method of claim 45, wherein the adaptor section is positioned between the target-specific section and the stem-forming section, and wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section.

47. The method of claim 46, wherein the adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.

48. The method of claim 45, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.

49. The method of claim 48, wherein the molecular indexing section is positioned between the target-specific section and the adaptor section.

50. The method of claim 49, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the adaptor section, and wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section and the molecular indexing sequence.

51. The method of claim 45, wherein the target-specific section comprises a 5'-

portion and a 3'-portion, and wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section.

52. The method of claim 51, wherein hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the adaptor section and the 5'-portion of the target-specific section.

53. The method of claim 51, wherein the loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

54. The method of claim 45, wherein the target-specific section comprises a 5'-portion and a 3'-portion, and wherein the stem-forming section is hybridizable to a 5'-portion of the target-specific section.

55. The method of claim 54, wherein hybridization between the stem-forming section and the 5'-portion of the target-specific section forms a loop that comprises the adaptor section but not the 3'-end portion of the target-specific section.

56. The method of claim 54, wherein the loopable primer further comprises one or more of G or C nucleotides positioned at the 5'-side of the target-specific section for stabilizing the stem structure with one or more complementary G or C nucleotides optionally positioned at the 3'-side of the stem-forming section.

57. The method of claim 45, wherein each pre-amplification cycle comprises annealing at least a forward loopable primer and a reverse loopable primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward loopable primer and the annealed reverse loopable primer.

58. The method of claim 41, wherein the primer is a split primer.

59. The method of claim 58, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.

60. The method of claim 59, wherein the molecular indexing section is positioned

between the adaptor section and one of the target-specific section.

61. The method of claim 60, wherein the molecular indexing section is positioned at 3' side of the adaptor section.

62. The method of claim 58, wherein each pre-amplification cycle comprises annealing at least a forward split primer and a reverse split primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward split primer and the annealed reverse split primer.

63. The method of claim 41, wherein the primer is a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section.

64. The method of claim 63, wherein the adaptor section is positioned between the stem-forming section and the second target-specific section, wherein hybridization between the stem-forming section and a portion of the second target-specific section forms a loop that comprises the adaptor section.

65. The method of claim 64, wherein the adaptor section is positioned at 5' side of the second target-specific section and 3' side of the stem-forming section.

66. The method of claim 65, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the second target-specific section that are not hybridizable to the stem-forming section.

67. The method of claim 63, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

68. The method of claim 67, wherein the molecular indexing section is positioned between the adaptor section and the second target-specific section.

69. The method of claim 68, wherein the molecular indexing section is positioned at 5' side of the second target-specific section and 3' side of the adaptor section, and wherein

hybridization between the stem-forming section and a portion of the second target-specific section forms a loop that comprises the adaptor section and the molecular indexing section.

70. The method of claim 63, wherein each pre-amplification cycle comprises annealing at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward split-loopable primer and the annealed reverse split-loopable primer.

71. The method of claim 41, wherein the primer is a split-loopable primer comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and an target-specific section.

72. The method of claim 71, wherein the second adaptor section is positioned between the stem-forming section and the target-specific section, wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section.

73. The method of claim 72, wherein the second adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.

74. The method of claim 71, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

75. The method of claim 74, wherein the molecular indexing section is positioned between the second adaptor section and the target-specific section.

76. The method of claim 75, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the second adaptor section, and wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section and the molecular indexing section.

77. The method of claim 76, wherein the target-specific section comprises a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section, and wherein hybridization between the stem-forming section and the

3'-portion of the target-specific section forms a loop that comprises the second adaptor section and the 5'-portion of the target-specific section.

78. The method of claim 77, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

79. The method of claim 71, wherein each pre-amplification cycle comprises annealing at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest to the template DNA or pre-amplification product thereof, and elongating the annealed forward split-loopable primer and the annealed reverse split-loopable primer.

80. The method of claim 41, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the method further comprises a plurality of PCR cycles using one or more PCR primers hybridizable to the universal adaptor sequence.

81. The method of claim 80, wherein the one or more PCR primers each comprises a sequencing adaptor and/or a sample barcode.

82. The method of claim 41, wherein each pre-amplification cycle comprises annealing at least 50 different primers each comprising a different stem-forming section to the template DNA or pre-amplification product thereof.

83. The method of claim 41, wherein each pre-amplification cycle comprises annealing at least 50 different primers each comprising a different molecular indexing sequence to the template DNA or pre-amplification product thereof.

84. The method of claim 41, wherein each pre-amplification cycle comprises annealing at least 2,500 different primers each comprising a different combination of the stem-forming section and the molecular indexing sequence to the template DNA or pre-amplification product thereof.

85. A kit for amplifying a target locus of interest, comprising a primer that is:

(a) a loopable primer comprising a target-specific section, an adaptor section, and a

stem-forming section, wherein the stem-forming section is hybridizable to a portion of the target-specific section to form a stem structure, or

(b) a split primer comprising a first target-specific section, a second target-specific section, and an adaptor section positioned between the first target-specific section and the second target-specific section, or

(c) a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, or comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section.

86. The kit of claim 85, further comprising a polymerase.

87. The kit of claim 85, further comprising a protease.

88. The kit of claim 85, further comprising one or more PCR primers hybridizable to the universal adaptor sequence.

89. The kit of claim 88, wherein the one or more PCR primers each comprises a sequencing adaptor and/or a sample barcode.

90. The kit of claim 85, wherein the primer is a loopable primer.

91. The kit of claim 90, wherein the adaptor section is positioned between the target-specific section and the stem-forming section, and wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section.

92. The kit of claim 91, wherein the adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.

93. The kit of claim 90, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.

94. The kit of claim 93, wherein the molecular indexing section is positioned between

the target-specific section and the adaptor section.

95. The kit of claim 94, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the adaptor section, and wherein hybridization between the stem-forming section and the portion of the target-specific section forms a loop that comprises the adaptor section and the molecular indexing sequence.

96. The kit of claim 90, wherein the target-specific section comprises a 5'-portion and a 3'-portion, and wherein the stem-forming section is hybridizable to the 3'-portion of the target-specific section.

97. The kit of claim 96, wherein hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the adaptor section and the 5'-portion of the target-specific section.

98. The kit of claim 96, wherein the loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

99. The kit of claim 90, wherein the target-specific section comprises a 5'-portion and a 3'-portion, and wherein the stem-forming section is hybridizable to a 5'-portion of the target-specific section.

100. The kit of claim 99, wherein hybridization between the stem-forming section and the 5'-portion of the target-specific section forms a loop that comprises the adaptor section but not the 3'-end portion of the target-specific section.

101. The kit of claim 99, wherein the loopable primer further comprises one or more of G or C nucleotides positioned at the 5'-side of the target-specific section for stabilizing the stem structure with one or more complementary G or C nucleotides positioned optionally at the 3'-side of the stem-forming section.

102. The kit of claim 90, comprising at least a forward loopable primer and a reverse loopable primer that target the same locus of interest for amplification.

103. The kit of claim 85, wherein the primer is a split primer.

104. The kit of claim 103, wherein the primer further comprises a molecular indexing section comprising a molecule indexing sequence.

105. The kit of claim 104, wherein the molecular indexing section is positioned between the adaptor section and one of the target-specific section.

106. The kit of claim 105, wherein the molecular indexing section is positioned at 3' side of the adaptor section.

107. The kit of claim 103, comprising at least a forward split primer and a reverse split primer that target the same locus of interest for amplification.

108. The kit of claim 85, wherein the primer is a split-loopable primer comprising a first target-specific section, a second target-specific section, and a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section.

109. The kit of claim 108, wherein the adaptor section is positioned between the stem-forming section and the second target-specific section, wherein hybridization between the stem-forming section and a portion of the second target-specific section forms a loop that comprises the adaptor section.

110. The kit of claim 109, wherein the adaptor section is positioned at 5' side of the second target-specific section and 3' side of the stem-forming section.

111. The kit of claim 110, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the second target-specific section that are not hybridizable to the stem-forming section.

112. The kit of claim 108, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

113. The kit of claim 112, wherein the molecular indexing section is positioned

between the adaptor section and the second target-specific section.

114. The kit of claim 113, wherein the molecular indexing section is positioned at 5' side of the second target-specific section and 3' side of the adaptor section, and wherein hybridization between the stem-forming section and a portion of the second target-specific section forms a loop that comprises the adaptor section and the molecular indexing section.

115. The kit of claim 108, comprising at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification.

116. The kit of claim 85, wherein the primer is a split-loopable primer comprising a first adaptor section, a second adaptor section, and a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section.

117. The kit of claim 116, wherein the second adaptor section is positioned between the stem-forming section and the target-specific section, wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section.

118. The kit of claim 117, wherein the second adaptor section is positioned at 5' side of the target-specific section and 3' side of the stem-forming section.

119. The kit of claim 116, wherein the split-loopable primer further comprises a molecular indexing section comprising a molecule indexing sequence.

120. The kit of claim 119, wherein the molecular indexing section is positioned between the second adaptor section and the target-specific section.

121. The kit of claim 120, wherein the molecular indexing section is positioned at 5' side of the target-specific section and 3' side of the second adaptor section, and wherein hybridization between the stem-forming section and a portion of the target-specific section forms a loop that comprises the second adaptor section and the molecular indexing section.

122. The kit of claim 116, wherein the target-specific section comprises a 5'-portion and a 3'-portion, wherein the stem-forming section is hybridizable to the 3'-portion of the target-

specific section, and wherein hybridization between the stem-forming section and the 3'-portion of the target-specific section forms a loop that comprises the second adaptor section and the 5'-end portion of the target-specific section.

123. The kit of claim 122, wherein the split-loopable primer further comprises one or more mismatched nucleotides at 3'-terminus of the target-specific section that are not hybridizable to the stem-forming section.

124. The kit of claim 123, comprising at least a forward split-loopable primer and a reverse split-loopable primer that target the same locus of interest for amplification.

125. The kit of claim 85, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification and/or sequencing.

126. The kit of claim 85, comprising a pool of at least 50 different primers each comprising a different stem-forming section.

127. The kit of claim 85, comprising a pool of at least 50 different primers each comprising a different molecular indexing sequence.

128. The kit of claim 85, comprising a pool of at least 2,500 different primers each comprising a different combination of the stem-forming section and the molecular indexing sequence.

129. A method for determining copy number variation of a target locus of interest, comprising:

pre-amplifying the target locus of interest from a template DNA using at least two pre-amplification cycles with: (a) one or more loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing

sequence, (b) one or more split-loopable primers each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, a molecular indexing section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, or (c) one or more split-loopable primers each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, a molecular indexing section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence;

amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and

sequencing the amplification product to determine copy number variation of the target locus of interest using the molecule indexing sequence.

130. A method for determining fetal aneuploidy, comprising:

pre-amplifying a plurality of target loci of interest of one or more chromosomes from cell-free DNA isolated from a maternal blood sample, using at least two pre-amplification cycles with: (a) a plurality of loopable primers each comprising a target-specific section, an adaptor section, a molecular indexing section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, (b) a plurality of split-loopable primers each comprising a first target-specific section,

a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, a molecular indexing section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section and the molecular indexing section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence, or (c) a plurality of split-loopable primers each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, a molecular indexing section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the molecular indexing section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the molecular indexing section comprises a molecule indexing sequence;

amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence; and

sequencing the amplification product to determine fetal aneuploidy using the molecule indexing sequence.

131. A method for multiplex amplification, comprising:

pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific

section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification;

and wherein the first primer and the second primer comprise complementary sequences in their target-specific sections and are capable of forming a primer dimer absent protection by the stem-forming section; and

amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence.

132. A method for allele-specific amplification, comprising:

pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) a loopable primer comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the loopable primer comprises an SNV or SNP allele in the 3'-portion of the target-specific section, (b) a split-loopable primer comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section comprises a universal adaptor sequence for PCR amplification, and wherein the split-loopable primer comprises an SNV or SNP allele in the target-specific section, or (c) a split-loopable primer comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-

specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections comprise a universal adaptor sequence for PCR amplification, and wherein the split-loopable primer comprises an SNV or SNP allele in the 3'-portion of the target-specific section; and

amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence.

133. A method for allele-specific quantitative PCR (qPCR), comprising:

pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe,

second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele;

amplifying the pre-amplification product using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and

detecting real-time intensity of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

134. A method for allele-specific digital PCR (dPCR), comprising:

pre-amplifying one or more target loci of interest from a template DNA using at least two pre-amplification cycles with: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe,

wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele;

partitioning the pre-amplification product into a plurality of reaction volumes;

amplifying the pre-amplification product in each reaction volume using one or more PCR primers hybridizable to the universal adaptor sequence in the presence of the first fluorescent probe and the second fluorescent probe; and

detecting presence or absence of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

135. A method for allele-specific quantitative PCR (qPCR), comprising:

amplifying one or more target loci of interest from a template DNA, in the presence of the first fluorescent probe and the second fluorescent probe, using: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and

wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele; and

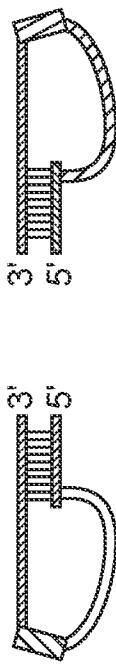
detecting real-time intensity of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

136. A method for allele-specific digital PCR (dPCR), comprising:
partitioning a sample comprising template DNAs into a plurality of reaction volumes;
amplifying one or more target loci of interest from a template DNA in each reaction volume, in the presence of the first fluorescent probe and the second fluorescent probe, using: (a) at least a first loopable primer and a second loopable primer each comprising a target-specific section, an adaptor section, and a stem-forming section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the adaptor section and the 5'-portion of the target-specific section, wherein the adaptor section of the first loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first loopable primer comprises a first SNV or

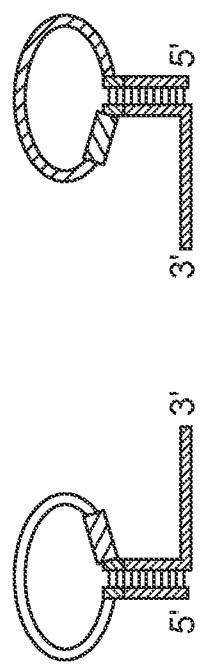
SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second loopable primer comprises a second SNV or SNP allele, (b) at least a first split-loopable primer and a second split-loopable primer each comprising a first target-specific section, a second target-specific section, a stem-forming section positioned between the first target-specific section and the second target-specific section, and an adaptor section, wherein the stem-forming section is hybridizable to a portion of the second target-specific section to form a stem structure and a loop comprising the adaptor section, wherein the adaptor section of the first split-loopable primer comprises a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the adaptor section of the second split-loopable primer comprises a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele, or (c) at least a first split-loopable primer and a second split-loopable primer each comprising a first adaptor section, a second adaptor section, a stem-forming section positioned between the first adaptor section and the second adaptor section, and a target-specific section, wherein the target-specific section comprises a 5'-portion and a 3'-portion and the stem-forming section is hybridizable to the 3'-portion of the target-specific section to form a stem structure and a loop comprising the second adaptor section and the 5'-portion of the target-specific section, wherein the first and/or second adaptor sections of the first split-loopable primer comprise a universal adaptor sequence for PCR amplification and a first probe-specific sequence capable of binding to a first fluorescent probe, wherein the first and/or second adaptor sections of the second split-loopable primer comprise a universal adaptor sequence for PCR amplification and a second probe-specific sequence capable of binding to a second fluorescent probe, wherein the 5'- or 3'-portion of the target-specific section of the first split-loopable primer comprises a first SNV or SNP allele, and wherein the 5'- or 3'-portion of the target-specific section of the second split-loopable primer comprises a second SNV or SNP allele; and

detecting presence or absence of fluorescent signal from the first fluorescent probe and the second fluorescent probe.

Scheme A: 3'-target-StemLoop



Scheme B: 5'-target-StemLoop



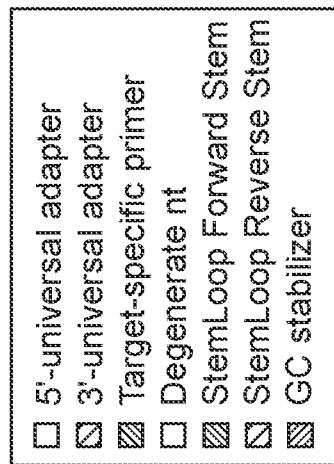
Scheme C: Split primer



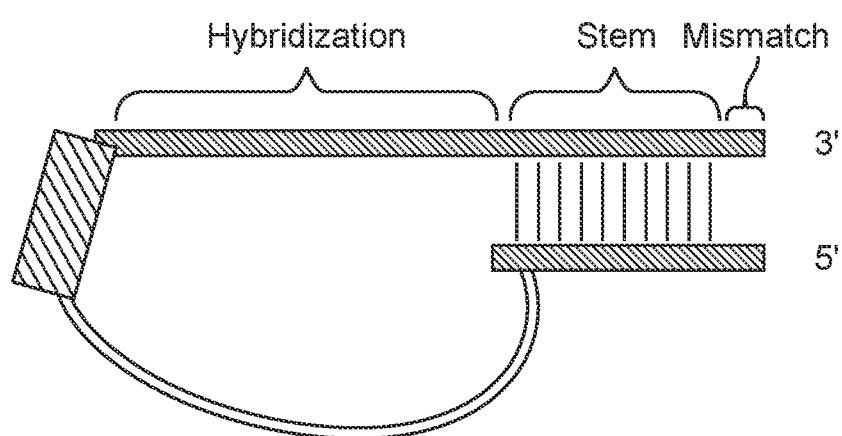
Control Scheme: standard degenerate primer



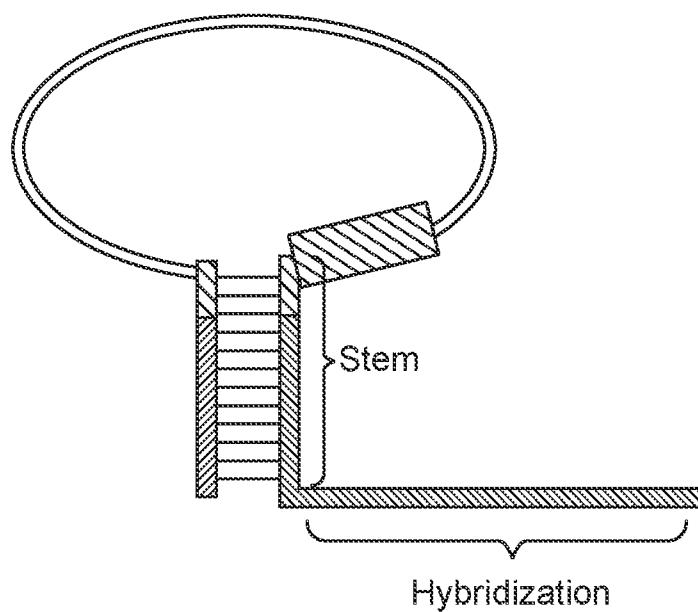
FIG. 1



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Scheme A: 3'-target-StemLoop**FIG. 2**

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Scheme B: 5'-target-StemLoop**FIG. 3**

Scheme C: Split primer**FIG. 4**

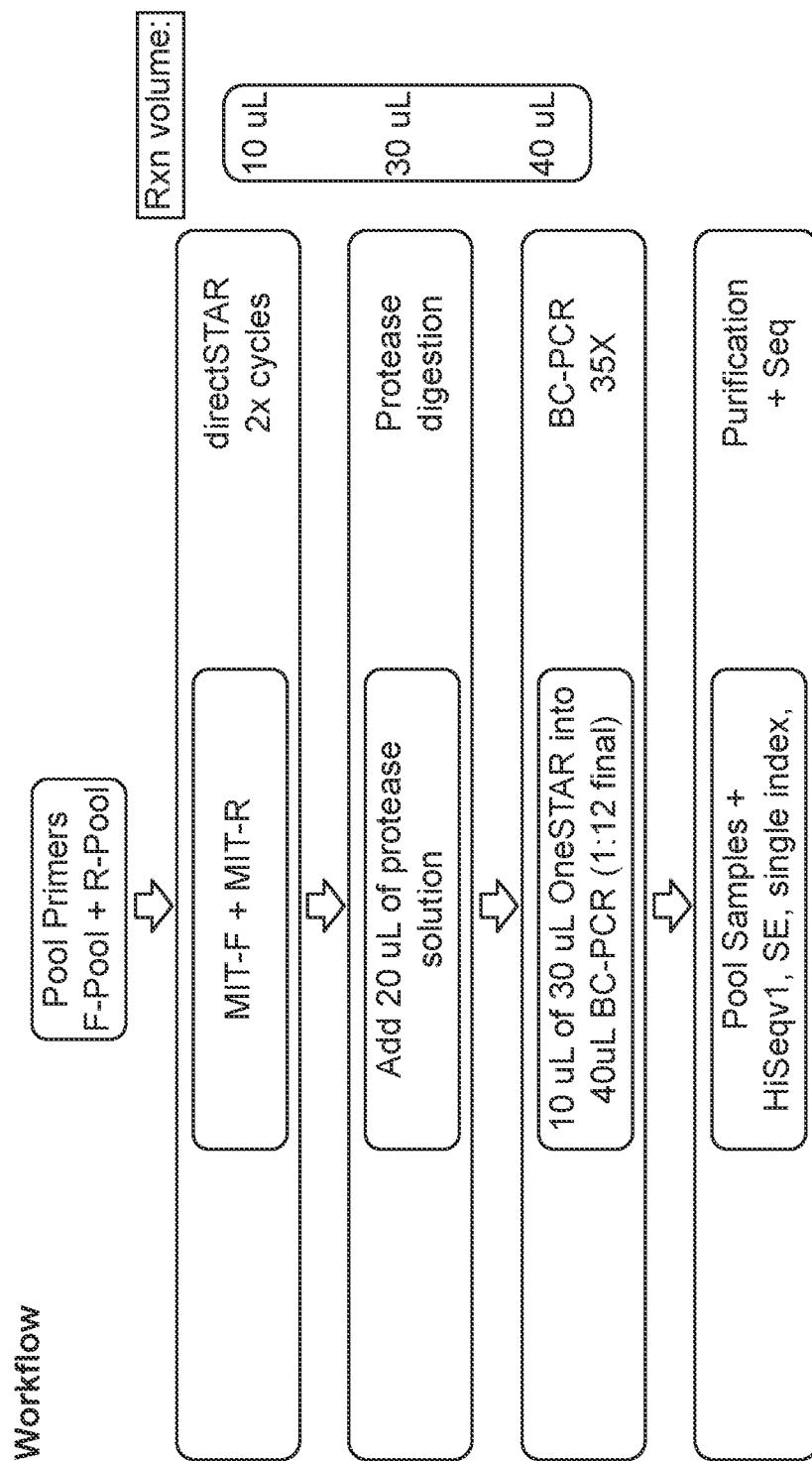


FIG. 5

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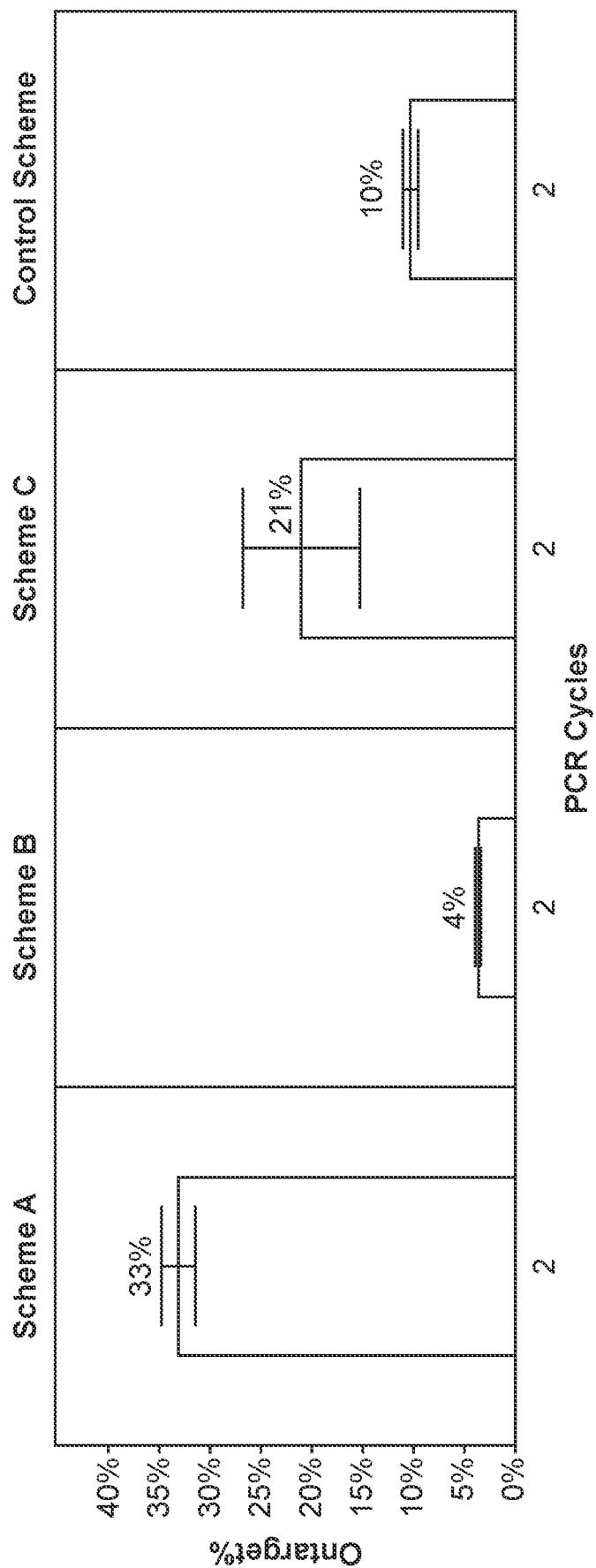


FIG. 6

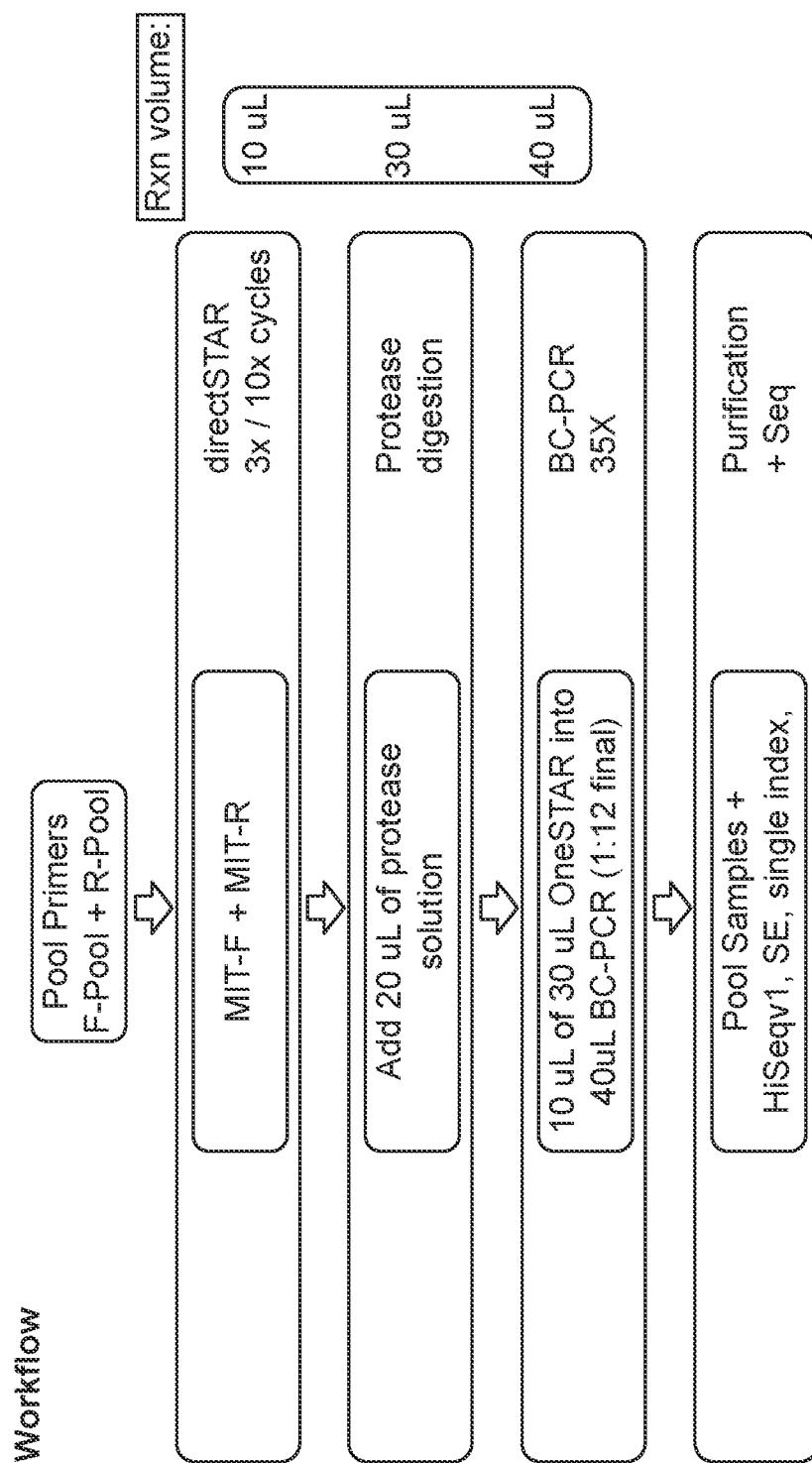


FIG. 7

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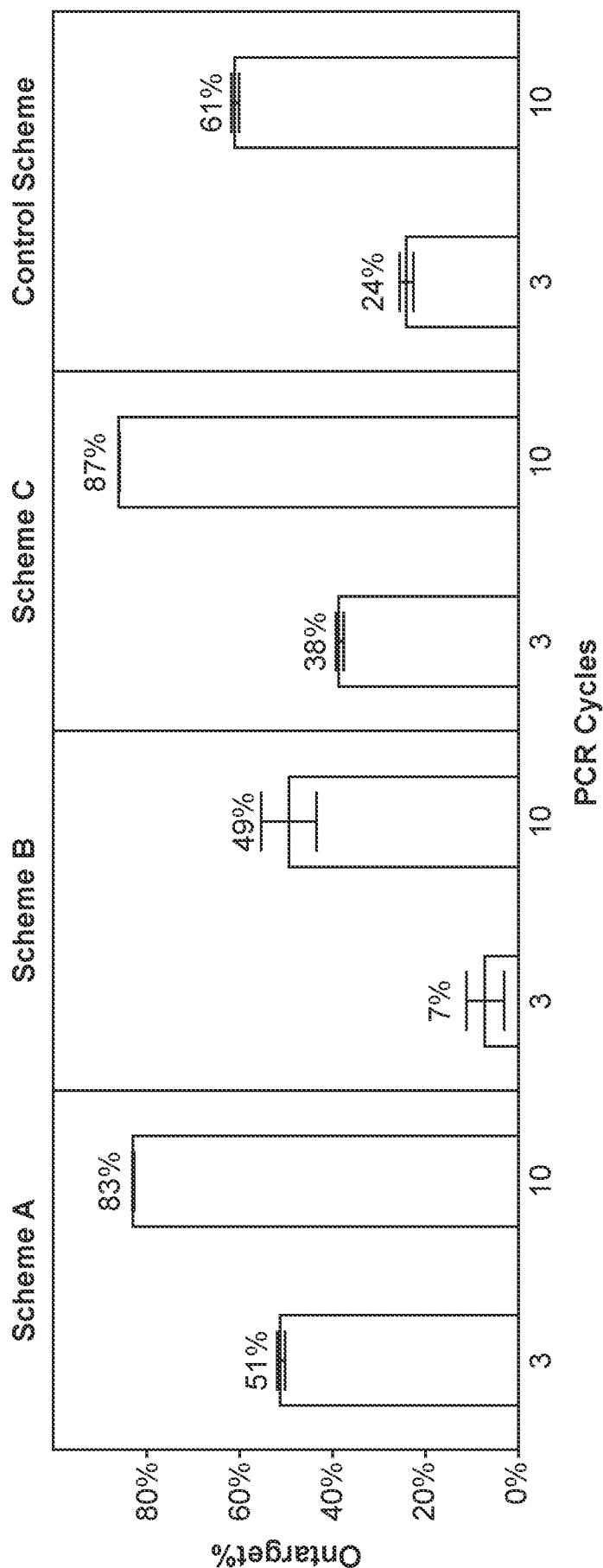


FIG. 8

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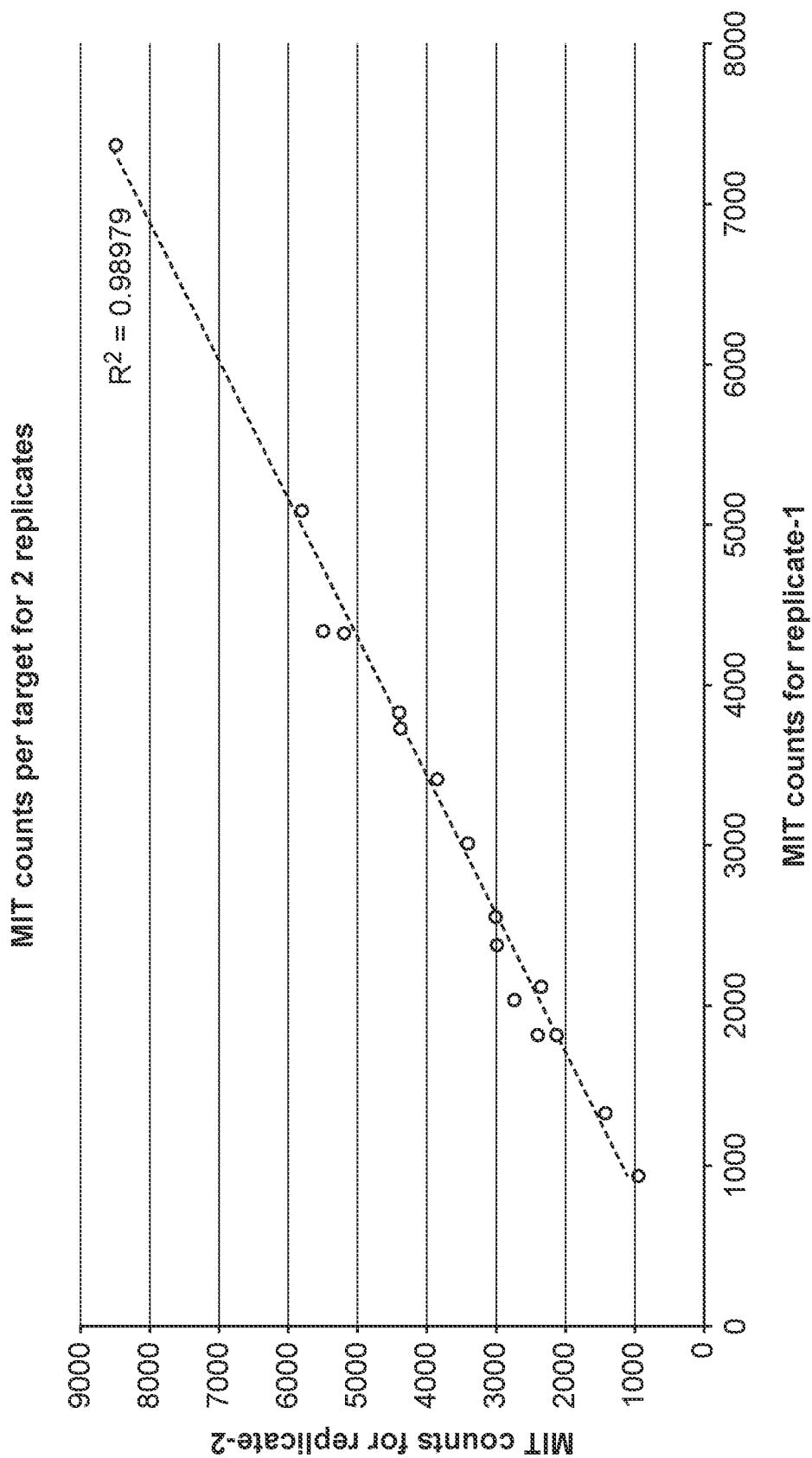
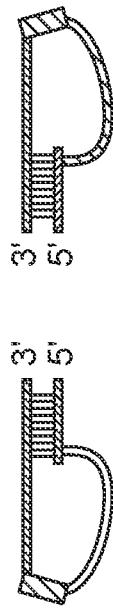


FIG. 9

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Scheme A



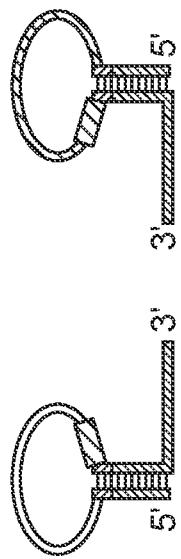
5'-Target stem loop primer (5'->3')	
Loop Forward Primer	5'-2nt-mismatch - reverse complement of 3' target-ACAGGACGGCTCTTCCGATCTNNNN-full primer sequence-3'
Loop Reverse Primer	5'-2nt-mismatch - reverse complement of 3' target-AGACGTGTGGCTCTTCCGATCTNNNN-full primer sequence-3'

Product Sequence:

Molecular Barcode

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Scheme B



5'-Target stem loop primer (5'->3')

5'-Target stem loop primer (5'->3')	
Loop Forward Primer	5'-reverse complement of 5' target primer-GGACACGAGCTCTTCCGATCTNNNNCC-full primer sequence-3'
Loop Reverse Primer	5'-reverse complement of 5' target primer -GGAGACGGTGGCTCTTCCGATCTNNNNCC-full primer sequence-3'

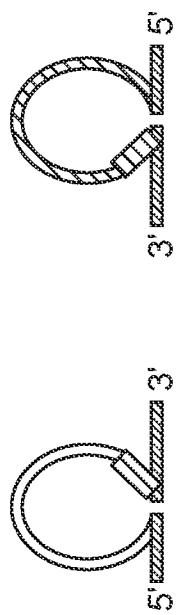
Product Sequence:

Molecular Barcode

5'-NN-NNGGAGACCAAGCTCTTCCGACTTCCNNNNAGATCGGAAGAGCCTCGTGTCCNN-3',
NN-NNNNAGATCGGAAGAGCCTCGTGTCCNNNNAGATCGGAAGAGCCTCGTGTCCNNNN-5'

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Scheme



Loop primer (5'->3')	Loop Forward Primer	5'-forward target-ACACGGACGCTCTTCCGATCTNNNN-3'-forward target primer
Loop Reverse Primer	Loop Reverse Primer	5'-reverse target-ACACGTGCTCTTCGGATCTNNNN-3'-reverse target primer

product sequence:

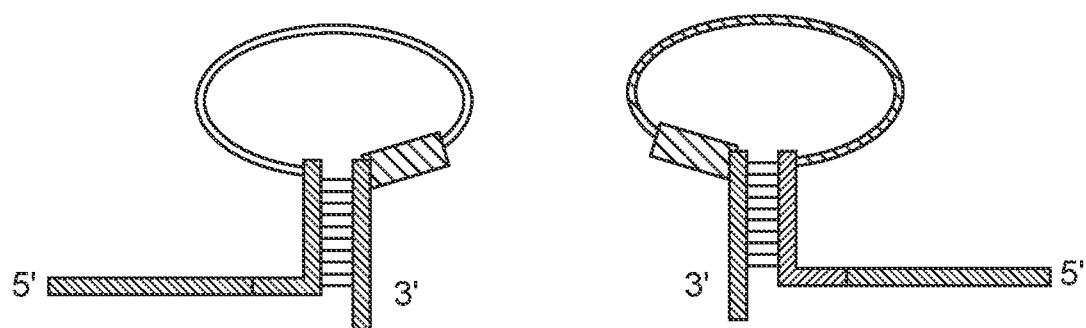
5' -F-primer
Molecular Barcode Target

5' -NN . NNACAGAACGCTTCCGATCTNNNNNN . . . NNNNNNAGATGGAAAGAGCACACGTCCTNN . . NN-3 ' 5' -NN . NNAGACGCTTCCGATCTNNNNNN . . . NNNNNNAGATGGAAAGAGCGTCGTCNN . . NN-3 ' 5' -R-primer

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FIG. 12

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Scheme D:**Scheme E:****FIG. 13**

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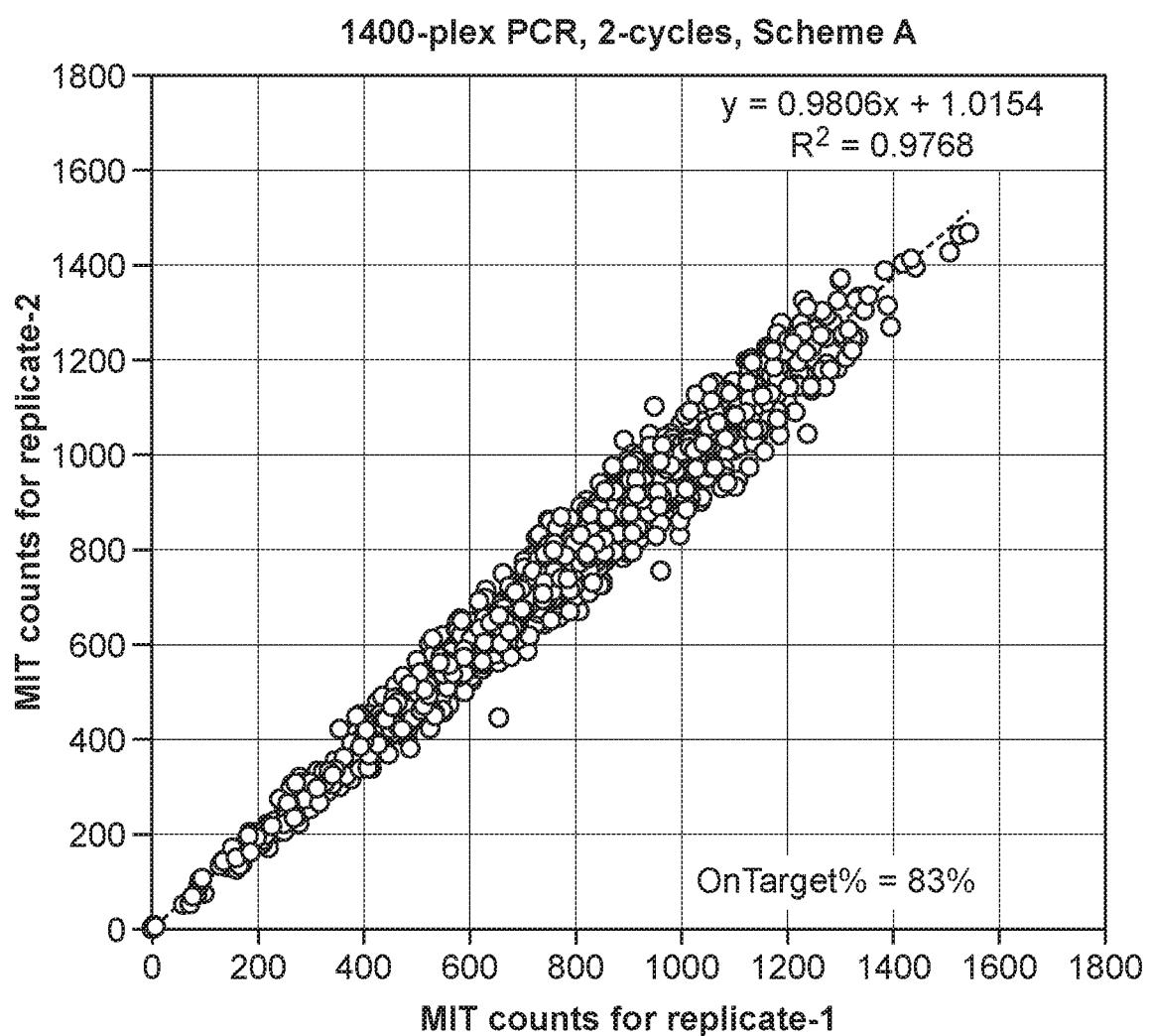
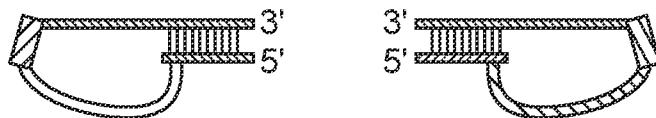


FIG. 14

Scheme A: 3'-target-StemLoop



Scheme B: 5'-target-StemLoop



- 5'-universal adapter
- 3'-universal adapter
- Target-specific primer
- Degenerate nt
- StemLoop Forward Stem
- StemLoop Reverse Stem
- GC stabilizer

Scheme C: Split primer



Control Scheme: standard degenerate primer



FIG. 1