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PLoS one

Molecular Detection of Eukaryotes in a Single Human Stool Sample from Senegal

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Abstract

Background: Microbial eukaryotes represent an important component of the human gut microbiome, with different beneficial or harmful roles; some species are commensal or mutualistic, whereas others are opportunistic or parasitic. The diversity of eukaryotes inhabiting humans remains relatively unexplored because of either the low abundance of these organisms in human gut or because they have received limited attention from a whole-community perspective.

Methodology/Principal Finding: In this study, a single fecal sample from a healthy African male was studied using both culture-dependent methods and extended molecular methods targeting the 18S rRNA and ITS sequences. Our results revealed that very few fungi, including Candida spp., Galactomyces spp., and Trichosporon asahii, could be isolated using culture-based methods. In contrast, a relatively a high number of eukaryotic species could be identified in this fecal sample when culture-independent methods based on various primer sets were used. A total of 27 species from one sample were found among the 977 analyzed clones. The clone libraries were dominated by fungi (716 clones/977, 73.3%), corresponding to 16 different species. In addition, 187 sequences out of 977 (19.2%) corresponded to 9 different species of plants; 59 sequences (6%) belonged to other micro-eukaryotes in the gut, including Entamoeba hartmanni and Blastocystis sp; and only 15 clones/977 (1.5%) were related to human 18S rRNA sequences.

Conclusion: Our results revealed a complex eukaryotic community in the volunteer's gut, with fungi being the most abundant species in the stool sample. Larger investigations are needed to assess the generality of these results and to understand their roles in human health and disease.

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Introduction

The human body is home to vast and complex communities of microorganisms. It has been estimated that microbes in human bodies collectively make up approximately 100 trillion cells, ten times the number of human cells [1]. The microbial ecosystem plays important role in human metabolic activities, protection against pathogens, nutrient processing, the stimulation of angiogenesis, and the regulation of host fat storage [2,3].

The human gut is dominated by bacteria, especially species of the phyla Firmicutes and Bacteroidetes. These two phyla are spread throughout the intestinal tract and play crucial roles in human health [4,5]. In addition to bacteria, organism belonging to other domains of life, Archaea and Eukarya, are present in the human intestine [4,6].

Microbial eukaryotes represent an important component of the human gut microbiome, with different beneficial or harmful roles; some species are commensal or mutualistic, whereas others are opportunistic or parasitic [7]. This eukaryotic component of the human gut microbiome remains relatively unexplored because these organisms have a low abundance in human gut or because they received a limited attention from molecular analyses [4,8]. Thus, studying the eukaryotic diversity in the human gut can provide more complete picture of the natural communities inhabiting this niche.

The microbial eukaryote communities in the human gut have been studied primarily using selective culture techniques and microscopy-based approaches [4,9,10]. Identification was based on morphological and physiological traits. However, only a small fraction of the microorganisms present has been detected using this approach because the growth requirements for many of these organisms remain unknown [4]. Recently, molecular-based approaches, such as polymerase chain reaction (PCR) amplification of the small subunit ribosomal RNA, have been established to explore the microbial diversity in the human body [4,11,12]. In 2006, Scupham and his colleagues undertook a culture-independent analysis of fungi in mouse feces, and they identified a wide variety of fungi belonging to the phyla Ascomycota, Basidiomycota, Chytridiomycota and Zygomycota using oligonucleotide fingerprinting of rRNA genes (OFRG) [13].

More recently, in the human distal gut, culture-independent methods have shown that the diversity and abundance of eukaryotes is quite low relative to that of bacteria, and members of the genera *Gloeotinia/Paecilomyces* and *Galactomyces* were the most abundant [14] (Table 1). A more diverse fungal community was

observed in the study of Ott et al., 2008, in which they investigated the mucosa-associated fungal microbiota in 47 controls and 57 subjects with inflammatory bowel disease. That study showed that the majority of fungi retrieved from the fecal sample belonged to Ascomycota [15] (Table 1). Only four types of fungi (*Candida vinaria*, *Candida edaphicus*, *Saccharomyces cerevisiae* and *Saccharomyces servazzii*) and one stramenopile (*Blastocystis hominis*) were detected in fecal samples from ten Korean people using the PCR-fingerprinting method [8] (Table 1). Finally, the ileal effluent and feces from 2 intestinal transplant patients were analyzed by Li et al. [16], who reported temporal alterations in the fungal communities in these patients (Table 1). An increase in the size of the fungal community early after intestinal transplantation, followed by a decrease in this community over time, was observed. Moreover, sequence analysis of the 18S ribosomal DNA revealed that *S. cerevisiae* and *Kluyveromyces waltii* were the dominant fungal species in both patients [16].

The aim of this study is to carry out a comprehensive extended molecular analysis of the diversity of eukaryotes in one fecal sample from a young Senegalese man using amplification with various universal primers followed by cloning and sequencing.

Results

Culture-dependent Methods

Using different media, five strains of fungi were isolated from one fecal sample. The results of MALDI-TOF identification were as follows: *Candida albicans*, *Candida krusei*, *Galactomyces geotrichum*, *Trichosporon asahii* and *Geotrichum silvicola* (Table 2). Direct ITS sequencing of these strains confirmed the results of the MALDI-TOF MS analysis for *C. krusei*, *G. geotrichum* and *T. asahii*. *C. albicans* and *G. silvicola* were misidentified using MALDI-TOF MS, and the correct identities of these strains were *Candida rugosa* and *G. geotrichum*, respectively (Table 2). Finally, taking into account the ITS results, only four species of fungi were recovered through culture-based methods.

Culture-independent Methods

An important part of this study was to choose suitable PCR primers for the amplification of eukaryote sequences in the human gastrointestinal tract. One major difficulty was the tendency to amplify background bacterial, plant/animal and human DNA, which are all potentially found in DNA extracted from human feces. Twenty-five different published eukaryotic PCR primer sets were tested on fecal DNA extracts from young, healthy Senegalese man (see Table S1). For all primer sets, with the exception of the primers listed in Table 3, a negative PCR signal was obtained. The negative results with some primers could be explained by either their low sensitivities for the eukaryotic communities in the human gut or the absence of the target microorganisms in the studied sample.

Cloning was performed prior to sequencing only when direct sequencing was problematic or when the obtained sequences were not clean sequences, indicating the amplification of sequences from more than one microorganism. Finally, all PCR products were cloned and then sequenced with the exception of primers E528F/Univ1391 and FunF/FunR, which amplified *Malassezia restricta* and *G. geotrichum*, respectively (Table 3). A total of 977 clones were collected from different clone libraries that were generated using various primers and a fecal sample from a healthy male. All but 9 of the resulting sequences have sequence similarity scores of $\geq$98% when compared with existing sequences in the GenBank database. The remaining 9 sequences have similarity scores of 92% with *Malassezia pachydermatis*, and these 9 sequences may be from putative new species.

Taking the different clone libraries together, one-quarter of the obtained sequences were distributed among Viridiplantae (187 clones, 9 plant species), Stramenopile (38 clones, *Blastocystis* sp.), Amoebozoa (21 clones, *Entamoeba hartmanni*), and human 18S rDNA sequences (15 clones) (Table 3). Three-quarters of the remaining sequences (716 clones) were identified as fungi, with 16 different fungal species belonging to Ascomycota (48.4%) and Basidiomycota (24.9%) (Table 3). Seven fungal species of Ascomycete yeasts were detected: *C. rugosa*, *G. geotrichum*, *S. cerevisiae*, *Arxiozyma telluris*, *Kluyveromyces hubeiensis*, *Torulaspora pretoriensis*, and *Sterigmatomyces elviae* (Table 3). Nine basidiomycetous yeasts were also recovered from the different clone libraries, including *Trichosporon caseorum*, *T. asahii*, *Trichosporon cutaneum*, *M. restricta*, *Malassezia globosa*, *M. pachydermatis*, *Asterophora parasitica*, *Bjerkandera adusta*, and *Phanerochaete steroids* (Table 3).

Discussion

The primary objective of this study was to evaluate the broad diversity of eukaryotes in a single fecal sample from an African male using both culture-dependent and extensive culture-independent methods.

Culture-dependent versus Culture-independent Methods in this Study

Our results revealed that when using culture-dependent methods, very few fungi, including *C. rugosa*, *C. krusei*, *G. geotrichum*, and *T. asahii*, could be isolated. Among these fungi, *C. rugosa* and *C. krusei* have been previously detected by culture-based methods [12,17]. Many studies using culture-dependent approaches have found fungi as the sole eukaryotes in the human microbiome of healthy individuals and immunocompromised patients [12,14,18,19].

The culture-independent methods revealed a more vast diversity of eukaryotes, especially fungi, in our fecal sample compared with the eukaryotes that were obtained by culture-dependent methods. Among the 977 clones that were generated using different primers, 716 clones (73.3%) were belonged to fungi and corresponded to 16 species (Table 3). Among these 16 species, only 3, *C. Rugosa*, *G. candidum* and *T. asahii*, have been cultured. This discrepancy is due to the fact that some species require both special growth media and special conditions to be cultured. Conversely, *C. krusei*, a fungus isolated by culturing, was not detected by culture-independent methods. This result could be explained by biases in the PCR amplification [20] and/or cloning bias [21]. Interestingly, in Chen's study, molecular methods did not identify *C. krusei* from fecal samples, but this fungus was found by culturing techniques [12].

Culture-independent Methods

Different PCR primers were used to evaluate the diversity of eukaryotes in the fecal sample, and these primers were adopted from previously published studies. Some of these primers were used previously to analyze eukaryotes in the human gut (Table S1), whereas other primers were used previously to analyze eukaryotes from aquatic environments rather than the human gut (Table S1). Among the 18 micro-eukaryotic species found in our study, seven species were detected by two or more primer sets, including *T. Caseorum*, *S. cerevisiae*, *Blastocystis* sp., *G. geotrichum*, *C. rugosa*, *M. restricta*, and *M. globosa* (Table 3 and Figure 1). The remaining 11 species (Table 3 and Figure 1) were amplified using only one primer set.

Table 1. The different eukaryotes previously detected by molecular methods in the human gut using universal 18S rDNA or ITS primers.

	Taxa	Eukaryotic species	References	Eukaryotic species	References
Fungi	Ascomycota	*Acremonium* sp.	[14]	*Iodophanus carneus**	[12]
		Ajellomyces capsulatus†	[16]	*Kluyveromyces waltii*†	[16]
		Ajellomyces dermatitidis†	[16]	*Madurella mycetomatis**	[15]
		Aspergillus clavatus†	[16]	*Ophiocordyceps caloceroides**	[12]
		*Aspergillus penicillioides**	[12]	*Paraphaeosphaeria filamentosa*	[15]
		Aspergillus versicolor†	[12]	*Penicillium chrysogenum**	[14,15]
		*Aureobasidium pullulans**	[12,15]	*Penicillium freii*†	[12]
		Botryotinia fuckeliana†	[15,16]	*Penicillium glabrum**	[15]
		*Candida albicans**	[12,14–16]	*Penicillium italicum**	[15]
		*Candida austromarina**	[12,15]	*Penicillium marneffei*†	[16]
		Candida dubliensis†	[15,16]	*Penicillium* sp.*	[12]
		Candida edaphicus	[8]	*Penicillium verruculosum**	[14]
		Candida glabrata	[15]	*Penicillum sacculum**	[15]
		*Candida intermedia**	[12]	*Pleospora herbarum**	[15]
		Candida krissii†	[12]	*Raciborskiomyces longisetosum*	[15]
		*Candida milleri**	[12]	*Saccharomyces bayanus*	[15]
		Candida parapsilosis†	[16]	*Saccharomyces cariocanus*	[15]
		*Candida solani**	[12]	*Saccharomyces castellii*†	[16]
		Candida sp.	[12]	*Saccharomyces cerevisia**	[8,12,14–16]
		*Candida tropicalis**	[12,16]	*Saccharomyces paradoxus*†	[12]
		*Candida vinaria**	[8]	*Saccharomyces servazzii**	[8]
		Cephalosporium sp.	[14]	*Saccharomyces* sp.†	[12]
		*Chaetomium globosum**	[12,15]	*Sclerotinia sclerotiorum**	[15,16]
		Chaetomium sp.*	[12]	*Sclerotium* sp.†	[15]
		Cladosporium cladosporioides†	[15]	*Septoria epambrosiae*	[15]
		Coccidioides immitis†	[16]	*Simplicillium lanosoniveum**	[12]
		Coccidioides posadasii†	[16]	*Simplicillium obclavatum**	[12]
		*Doratomyces stemonitis**	[12]	*Sirococcus conigenus**	[15]
		Dothideomycete sp.†	[15]	*Trichophyton verrucosum*†	[16]
		*Fusarium oxysporum**	[15,16]	Uncultivatable Pezizomycotina†	[12]
		Fusarium sp.*	[12]	Uncultured ascomycete†	[15]
		*Galactomyces geotrichum**	[12,14–16]	*Verticillium leptobactrum*	[14]
		Gloeotinia temulenta	[14]	*Yarrowia lipolytica**	[15]
		*Hyphozyma variabilis**	[12]		
	Basidiomycota	*Asterotremella albida**	[12]	*Rhodotorula mucilaginosa*†	[15]
		Bullera crocea†	[15]	*Sporolobomyces yunnanensis**	[15]
		Cryptococcus carnescens	[15]	*Trametes versicolor**	[15]
		*Cryptococcus fragicola**	[12]	*Tricholoma saponaceum**	[15]
		Cryptococcus neoformans†	[16]	*Trichosporon dermatis**	[15]
		*Cystofilobasidium capitatum**	[15]	Uncultivatable Agaricomycotina*	[12]
		Dacrymyces sp.*	[15]	Uncultivatable Pucciniomycotina†	[12]
		Exidiopsis calcea†	[15]	Unculture basidiomycete	[15]
		*Filobasidium globisporum**	[15]	Uncultured basidiomycete†	[15]
		*Flammulina velutipes**	[15]	Uncultured ustilaginomycete†	[15]
		*Fomitopsis pinicola**	[15]	*Ustilago maydis*†	[15]
		*Graphiola phoenicis**	[15]	*Ustilago* sp.†	[15]
		Malassezia globosa†	[16]	*Wallemia muriae**	[12]
		Malassezia pachydermatis†	[12]	*Wallemia sebi**	[12]

Table 1. Cont.

	Taxa	Eukaryotic species	References	Eukaryotic species	References
		*Rhodotorula aurantiaca**	[15]		
	Zygomycota	*Rhizopus microsporus**	[12]		
	Amoebozoa	*Entamoeba coli*	[14]		
	Stramenopiles	*Blastocystis* sp.	[8,14]		
Plant	Viridiplantae	*Desmaria mutabilis*	[8]	*Physocarpus opulifolius**	[8]
		Hypseocharis pimpinellifolia†	[8]	*Rubus idaeus**	[8]
		*Parmentiera cereifera**	[8]	*Ziziphus obtusifolia**	[8]
		*Pelargonium alchemilloides**	[8]		

*Eukaryotes detected in both healthy and patient gut.
†Eukaryotes detected only in patient gut.
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Interestingly, the amplification of eukaryotic species using different sets of primers enabled us to obtain a relatively high number of species in the stool sample compared with the number of species obtained in previous molecular studies of this domain [8,12,14–16] (Figure 1). Three species identified in our sample were also found in these previous studies, including *G. geotrichum*, *S. cerevisiae*, and *Blastocystis* sp. (Figure 1). However, discordances were widespread, with many species detected only in our study and many species described previously in the human gut but not found in our work (Figure 1). These disagreements in the results may be due to many reasons. First, in our work, we studied only one fecal sample, but we used multiple universal primer sets; in contrast, in the previous studies many fecal samples were analyzed with one universal primer set [8,12,14–16]. Second, our sample was taken from a young, healthy African man, whereas the samples used in the other studies were obtained from patients with different diseases and conditions (hepatitis B virus infection, inflammatory bowel disease and post-transplantation intestine) and from patients from other geographic areas (Europe and Asia). Finally, another explanation for these discordances could be bias in the PCR and/or cloning.

Fungi are the Dominant Eukaryotes in the Human Gut

The results obtained from the sequencing of different clone libraries that were generated with various primers showed that fungi are the dominant eukaryotes in our fecal sample from Senegal. Approximately 16 fungi species were identified in the stool sample. This result is in agreement with the results of previous studies showing that fungi are widely distributed or abundant in the human gut [8,12,15].

Ascomycete Yeast in the Human Gut

Seven types of Ascomycete yeast were detected in the fecal sample using molecular methods. Among these yeasts, only *C. rugosa* and *G. geotrichum* were detected by culture-dependent methods. These species were identified using both direct ITS sequencing and analysis of the ITS clone library. The presence of these types of fungi was supported when their sequences retrieved from another 18S rRNA clone library using the JVF/DSPR2 primer. *C. rugosa* is considered to be widely distributed and abundant in the human intestine [6].

In addition, our study showed that *G. geotrichum* was widely retrieved from most of the generated clone libraries, accounting for 354 clones/977 (36.2%). This result agrees with the results of a previous study [14], in which *G. geotrichum* was most frequently found in the distal human gut using culture-independent methods. *S. cerevisiae* was also identified in the fecal sample from Senegal in the 18S rRNA clone libraries constructed using the Euk1A/Euk516r primers and the JVF/DSPR primers. This result is also in agreement with the results of previous studies [8,14–16].

To the best of our knowledge, the remaining four Ascomycete yeasts (*A. telluris*, *K. hubeiensis*, *T. pretoriensis*, and *S. elviae*) have not been described previously in the healthy human gastrointestinal tract. Thus, this report is the first these eukaryotic species in a stool sample. All of these species were found in environmental samples, including soil and leaf samples, except for *S. elviae*, which was isolated from two patients with eczematous skin lesions [22].

Basidiomycete Yeast in the Human Gut

Nine species of Basidiomycete yeast were identified from the different clone libraries generated using various primers in this study. Three species of *Trichosporon*, namely, *T. caseorum*, *T. asahii*, and *T. cutaneum*, were retrieved from the Senegalese stool sample

Table 2. Comparison of the cultured fungi identified by both MALDI-TOF MS and direct ITS sequencing.

MALDI-TOF MS	Best score of MALDI-TOF	Direct ITS	Identity %	Coverage %
Candida albicans	2.113	*Candida rugosa*	99	100
Candida krusei	2.189	*Candida krusei*	99	100
Galactomyces geotrichum	2.044	*Galactomyces geotrichum*	99	100
Trichosporon asahii	1.989	*Trichosporon asahii*	99	100
Geotrichum silvicola	2.064	*Galactomyces geotrichum*	99	100

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Table 3. Summary of resulting clone libraries in our study.

Name of primer	Fungal/Micro-eukaryotes species	No. of Clone/Total	Plant/human	No. of Clone/Total
Euk1A/Euk516r	*Trichosporon caseorum*	08/115	*Humulus lupulus*	64/115
	Saccharomyces cerevisiaei	06/115	*Artemisia annua*	23/115
	Blastocystis sp.	01/115	*Triticum aestivum*	01/115
	Trichosporon cutaneum	11/115	*Cupressus gigantea*	01/115
ITS F/ITS-4R	*Trichosporon asahii*	29/144		
	Galactomyces geotrichum	99/144		
	Candida rugosa	16/144		
E528F/Univ1391	*Malassezia restricta*	Direct sequencing		
E528F/Univ1492	*Malassezia globosa*	34/98	*Cupressus gigantea*	03/98
	Malassezia restricta	44/98	*Pinus luchuensis*	02/98
			Human 18s rRNA	15/98
JVF/DSPR2	*Saccharomyces cerevisiae*	17/132	*Humulus lupulus*	87/132
	Galactomyces geotrichum	02/132	*Solanum lycopersicum*	02/132
	Candida rugosa	03/132	*Triticum aestivum*	01/132
	Arxiozyma telluris	01/132	*Schinus molle*	01/132
	Trichosporon caseorum	14/132	*Phoenix canariensis*	01/132
	Torulaspora pretoriensis	01/132		
	Kluyveromyces hubeiensis	01/132		
	Asterophora parasitica	01/132		
NSI/FR1	*Galactomyces geotrichum*	52/96		
	Geotrichum candidum	44/96		
MF/MR	*Malassezia globosa*	79/96		
	Malassezia restricta	04/96		
	Malassezia pachydermatis	09/96		
	Sterigmatomyce elviae	02/96		
	Bjerkandera adusta	01/96		
	Phanerochaete stereoides	01/96		
EK1F/EK-1520	*Galactomyces geotrichum*	59/96		
	Blastocystis sp.	37/96		
121F/1147R	*Entamoeba hartmanni*	21/104	*Bomax ceiba*	1/104
	Galactomyces geotrichum	74/104		
	Trichosporon sp.	8/104		
FunF/FunR	*Galactomyces geotrichum*	Direct sequencing		
EUKA/EUKB	*Galactomyces geotrichum*	24/96		
	Candida rugosa	72/96		
11 primer sets	18 micro-eukaryotic species	775/977	10 species	202/977

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(Table 3). The genus *Trichosporon* is widely found in the environment, but it can occasionally be found in the gastrointestinal microbiota and can colonize human skin and the respiratory tract [23]. The three *Trichosporon* species found in our sample were not detected by previous molecular studies (Figure 1). Only *T. asahii,* which was detected by both culture-dependent and culture-independent methods in our study, has been isolated from a stool sample of 22 month-old boy with acute myeloid leukemia [24].

Malassezia, a fastidious basidiomycetous yeast, was also found in the Senegal stool sample represented by three species *M. restricta*, *M. globosa*, and *M. pachydermatis*. *Malassezia* could be found naturally on human skin but it is also able to cause cutaneous and systematic diseases [25]. Among these three species of *Malassezia*, M. *pachydermatis* and *M. globosa* have been detected previously in stool sample from health volunteers and intestinal transplant patients, respectively [12,16]. Thus, this study is the first report of molecular detection of *M. restricta* in human fecal sample (Figure 1).

The remaining three fungi belonged to *Basidiomycota* including *A. parasitica, B. adusta,* and *P. steroids* were not reported previously in human stool sample. Among these environmental species only *B. adusta* was previously isolated from human samples including sputa, bronchial washing and skin [26].

Other Eukaryotes in Human Gut

As well as the 16 fungal species discovered among the clone sequences, two micro-eukaryotic species were also detected (*Entamoeba hartmanni* and *Blastocystis* sp). *E. hartmanni*, which resides in the large intestine of man, is now considered to be a distinct

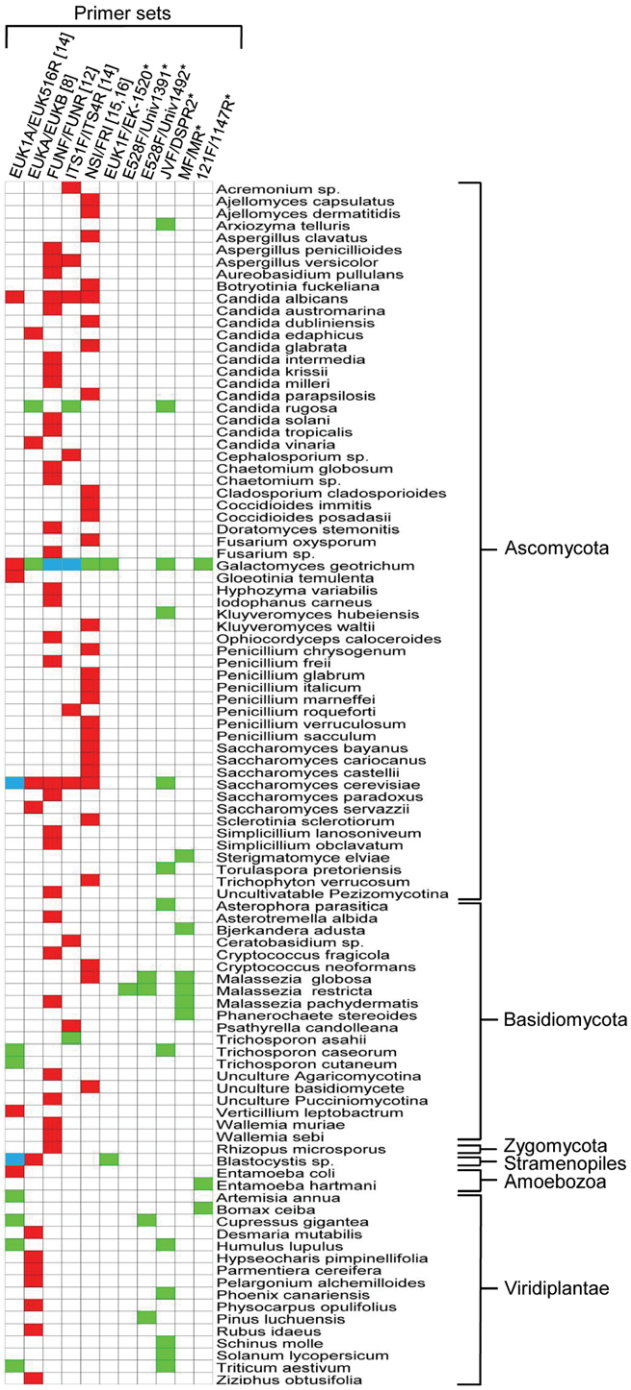


Figure 1. Comparison of our molecular results and those obtained previously for the human stool samples [8,12,14–16] using various universal primers. The universal primers used previously for the analysis of the human gut are indicated by the number of the reference. * indicates primers used for the first time to describe the human eukaryotic microbiota. Green color box = species positive in our sample and negative in the former studies; blue color box = species positive in both our sample and in the former studies; red color box = species negative in our sample and positive in the former studies.
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strain or species that is nonpathogenic and smaller than *E. histolytica* but otherwise indistinguishable from it [27]. *Blastocystis* sp also retrieved from the stool sample from Senegal, and this result concur with the study of Scanlan [14] in which *Blastocystis* was the dominant eukaryote in healthy human distal colon. Thus it may not cause disease. However, this unicellular, obligatory anaerobic protist could be common and prevalent in human with gastrointestinal illness like diarrhea and irritable bowel syndrome [28].

Finally, 9 different species of plants were detected in our sample (19.2% of the sequenced clones), with *H. lupulus* accounting for 15.5% of total sequenced clones (Table 3). The co-amplification of plant sequences with micro-eukaryote sequences has been reported previously in the literature [8] and may be due to the use of nonspecific and universal primers targeting the 18S rRNA gene. Some of these plants are consumed either as part of the diet or as a dietary supplement, including *T. aestivum*, *S. lycopersicum* and *P. canariensis*, and others plants are used as traditional medicines (e.g., *A. annua* as an anti-malarial [29], *H. lupulus* as an anxiolytic calming agent [30], and *B. ceiba* as an antioxidant [31]). The consumption of plants could explain the presence of these sequences in the stool sample.

In conclusion, we studied the eukaryotic diversity in one fecal sample from a healthy African man using extensive molecular methods with different sets of universal primers. Fungi largely dominated the clone libraries. The application of our molecular strategy in larger studies with a greater sample size, including people living in various geographic regions, is currently needed to better evaluate the occurrence/diversity of eukaryotes inhabiting the human gut and to correlate the presence of eukaryotes with human metabolism or disease. Moreover, expanded sequencing analysis using high-throughput pyrosequencing will expand the known diversity of eukaryotes in the healthy gut in the future.

Materials and Methods

Culturing and Identification of Eukaryotes

The fecal sample was obtained from a healthy 16-year-old Senegalese man living in Dielmo (a rural village in the Guinean-Sudanian zone in Senegal). Written assent was obtained from this individual; no written informed consent was needed from his guardians for this study because he was older than 15 years old (in accordance with the previous project approved by the Ministry of Health of Senegal and the assembled village population and as published elsewhere [32]). Both this study and the assent procedure were approved by the National Ethics Committee of Senegal (CNERS) and the Ethics Committee of the Institute Fédératif de Recherche IFR 48, Faculty of Medecine, Marseille, France (agreement number 09-022). The sample was serially diluted, and fivefold dilutions were spread-plated in triplicate on different media, including Sabouraud dextrose agar (BD Diagnostics, Heidelberg, Germany), Columbia culture media (BD Diagnostics, Heidelberg, Germany) and glycine-vancomycin-polymyxin B (GVPC) culture media (Biomérieux, Marcy l' Étoile, France). The plates were incubated aerobically for 48–72 h at 30 and 37°C. Colonies exhibiting different morphologies were restreaked to obtain pure cultures. The fungi were identified using matrix-assisted laser desorption ionization time-of-flight (MALDI-TOF) mass spectrometry (MS) (Microflex, Bruker Daltonics). The spectra obtained were compared with the Bruker Taxonomy database. Finally, direct internal transcribed spacer (ITS) analysis was performed for the fungal isolates as described previously to confirm the results of MALDI-TOF MS.

DNA Extraction

DNA was extracted from the frozen sample using a modified method for the Qiagen stool procedure (QIAamp DNA Tissue Kit, Qiagen Inc, Germany) [14]. Aliquots of 200 mg of fecal

sample were placed in 2 ml tubes containing a 200 mg mixture of 0.1, 0.5, and 22 m mm zirconium beads and 1.5 ml of ASL buffer (Qiagen). The sample was bead beaten at 3200 rpm for 90 seconds, followed by heating at 95°C for 10 minutes. The final pellet was suspended in 180 µl of tissue lysis buffer and incubated with proteinase K for 2 hours at 55°C. Then, the manufacturer's recommendations were followed for the purification and elution of the DNA.

Primer Selection

Twenty-two different published universal eukaryotic or fungal-specific PCR primer sets targeting the 18S rDNA and ITS sequences were used, as shown in Table S1. In addition, three specific primers for *Malassezia*, Rhodophyta, and Chlorophyta targeting the 28S rDNA, RUBISCO, and rps11-rp12 sequences, respectively, were also used (Table S1).

Genomic Amplification

Amplifications of sections of approximately 250–1,700 bp were carried out with the primers listed in Table S1. The PCR reaction mixture (final volume, 50 µl) contained 5 µl of dNTPs (2 mM of each nucleotide), 5 µl of 10x DNA polymerase buffer (QIAGEN, Courtaboeuf, France), 1 µl of MgCl2 (25 mM), 0.25 µl of HotStarTaq DNA polymerase (5 U) (QIAGEN, Courtaboeuf, France), 1 µl of each primer (Table S1) (10 pmol/µl), and 5 µl of extracted DNA. PCR was performed with a preliminary step at 95°C for 15 minutes; 40 cycles of 95°C for 45 seconds, annealing at the appropriate temperature for the primers used (see Table S1) for 30 seconds, and 72°C for 1 to 2 minutes; and a final extension step at 72°C for 5 minutes. The PCR products were analyzed using agarose gel electrophoresis and visualized by ethidium bromide staining. Then, the positive PCR products were purified using the NucleoFast® 96 PCR Kit (MACHEREY-NAGEL, Hoerdt, France) according to the manufacturer's instructions.

Cloning Procedures and Insert Amplification

Cloning of the purified PCR products was performed using the pGEM® -T Easy Vector System 2 Kit (Promega, Madison, USA) as recommended by the manufacturer. All white colonies were collected and then analyzed by PCR M13 as described previously [33].

Sequencing and Informative Data Analysis

Purified PCR-M13 inserts were sequenced in both directions using the Big Dye® Terminator V1,1 Cycle Sequencing Kit (Applied Biosystems, Courtaboeuf, France). The primers used for sequencing were M13d and M13r. The sequencing products were then run on an ABI PRISM 3130 automated sequencer (Applied Biosystems, Foster City, CA, USA). Finally, the eukaryotes were identified by comparing the obtained sequences with existing sequences in the GenBank database using the BLAST program available at the National Center for Biotechnology Information Web site (http://www.ncbi.nlm.nih.gov/, BLAST).

Nucleotide Sequence Accession Numbers

All sequences obtained in this work have been deposited in GenBank database with the accession numbers JX131688 to JX132666.

Supporting Information

Table S1 Primers used in this study.
(DOCX)

Author Contributions

Conceived and designed the experiments: DR FB. Performed the experiments: IH. Analyzed the data: IH CS DR FB. Contributed reagents/materials/analysis tools: IH CS. Wrote the paper: IH DR FB.

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