

Random Excitation by Optimized Pulse Inversion in Contrast Harmonic Imaging

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Outline

- 1 Introduction
 - Ultrasound Contrast Imaging
 - Pulse Inversion Imaging
 - Problematic
- 2 Random Excitation
 - Principle
 - Simulation Model
 - Results for linear system
 - Results for nonlinear pulse inversion imaging system
- 3 Parametric Optimization
 - Implementation
 - Results
- 4 Conclusions & Prospects

Introduction

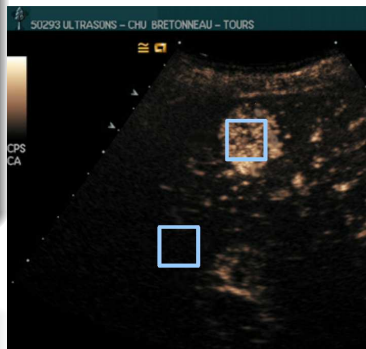
Ultrasound Contrast Imaging

Contrast Agents

- Injection of contrast agents \Rightarrow perfusion imaging
- Encapsulated microbubbles: mean diameter between 1 to 10 μm
- High nonlinear behavior

Contrast to Tissue Ratio

$$CTR = \frac{E_{\text{microbubbles}}}{E_{\text{tissue}}}$$



[F. Tranquart]

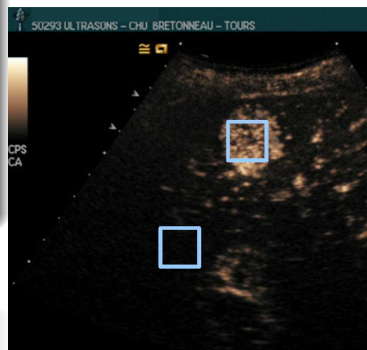
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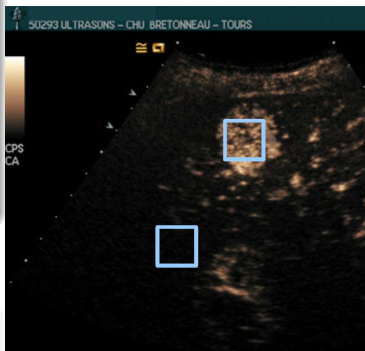
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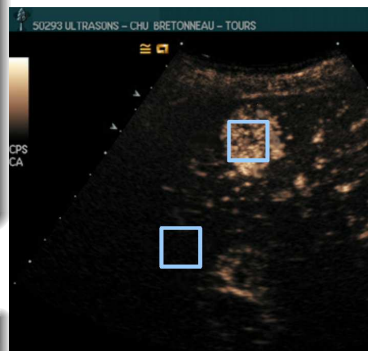
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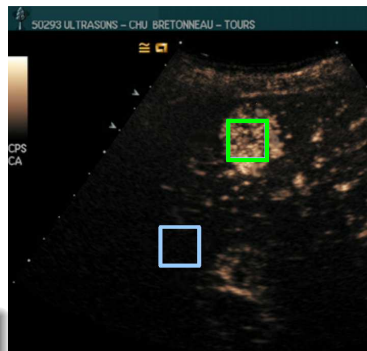
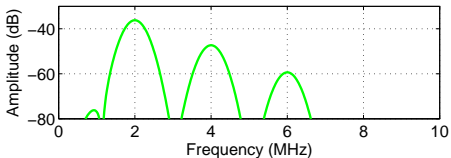
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[F. Tranquart]

Ultrasound Contrast Imaging

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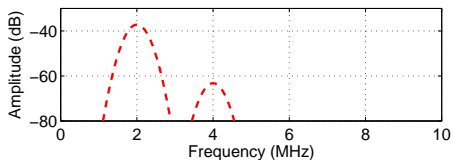
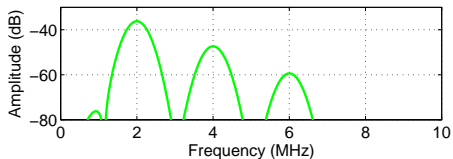
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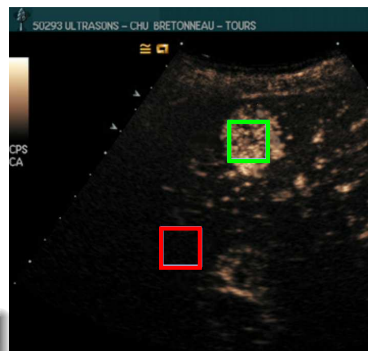
Ultrasound Contrast Imaging

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Contrast to Tissue Ratio

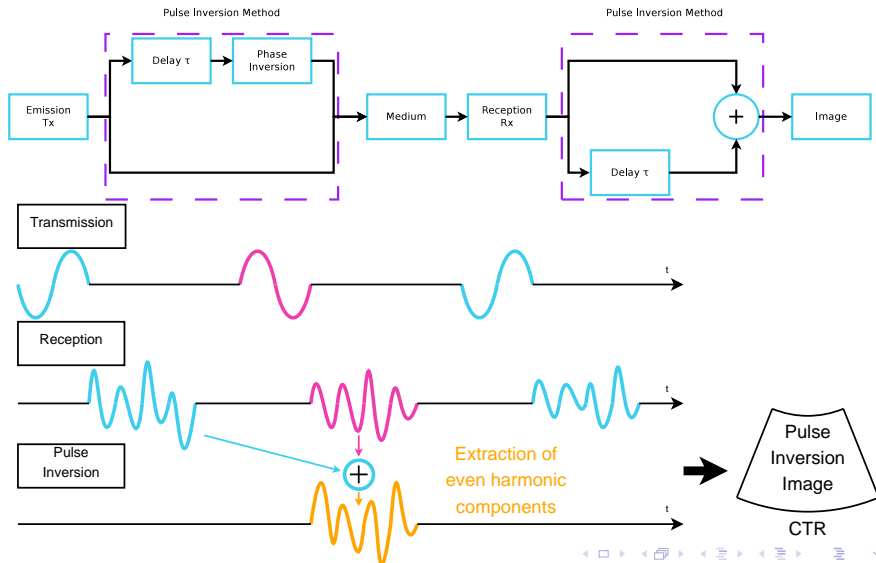
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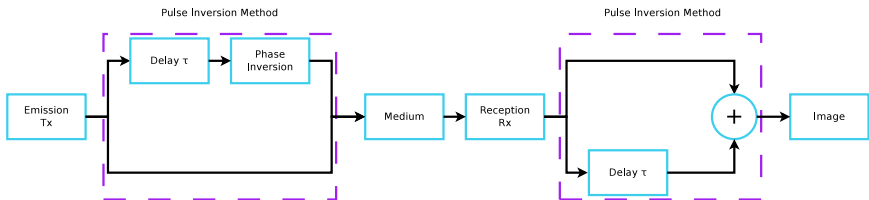
[F. Tranquart]

Pulse Inversion Imaging

Pulse Inversion Imaging



What is the best command to optimize the *CTR*?



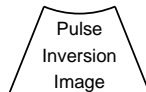
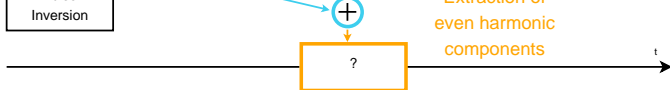
Transmission



Reception



Pulse Inversion

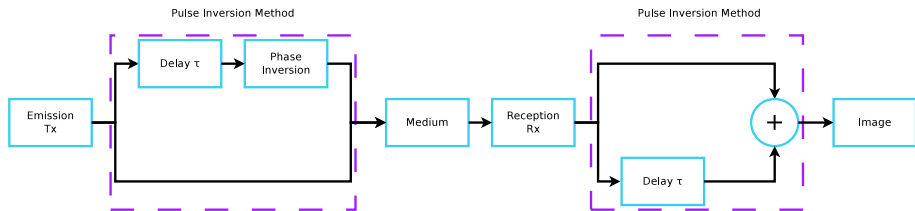
**OPTIMAL****CTR**

Random Excitation

- Automatic
- Without hypothesis on the shape wave

Principle

Principle of Random Excitation

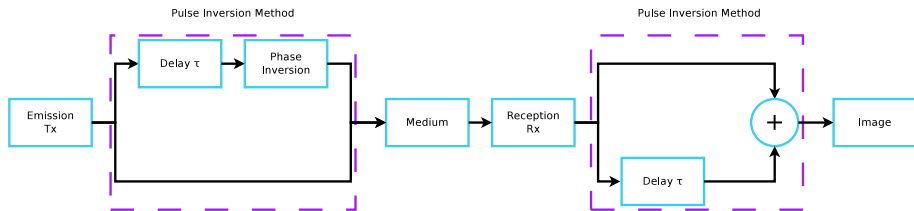


Principle of Implementation

- 1 Find the input signal $x(t)$ of the pulse inversion imaging system
- 2 Optimize the CTR
- 3 Random search by Monte-Carlo method

Principle

Principle of Random Excitation

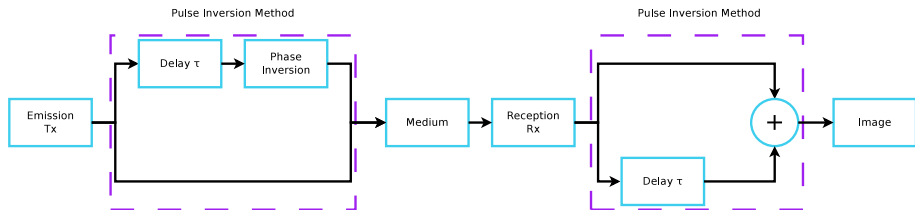


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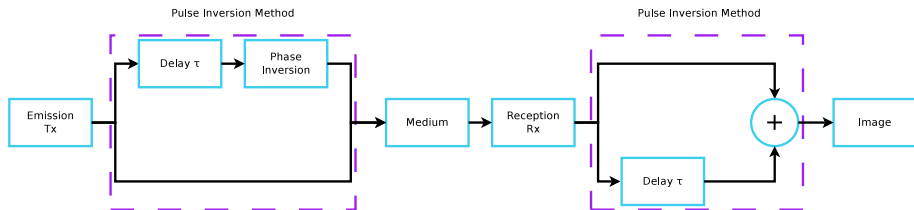


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Principle of Implementation

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Simulation Model

Simulation Properties

- Transducer centred at $f_c = 3$ MHz
- Microbubble
 - Free simulation software Bubblesim [Hoff, 2001]
 - Modified Rayleigh-Plesset Equation
 - Diameter: $2.5 \mu\text{m}$
 - Shell thickness: 1 nm
 - Resonance Frequency: 3.1 MHz
- Tissue : Rayleigh diffusion

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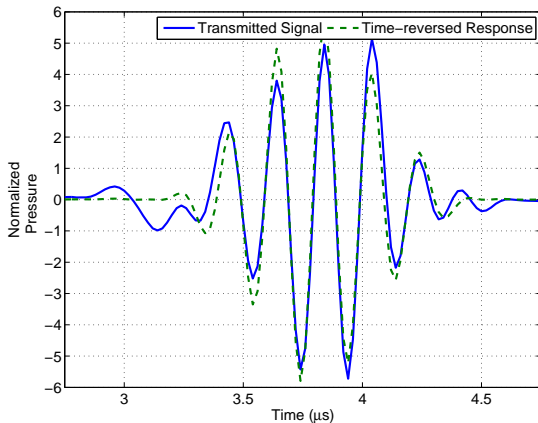
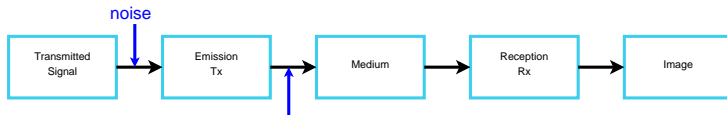
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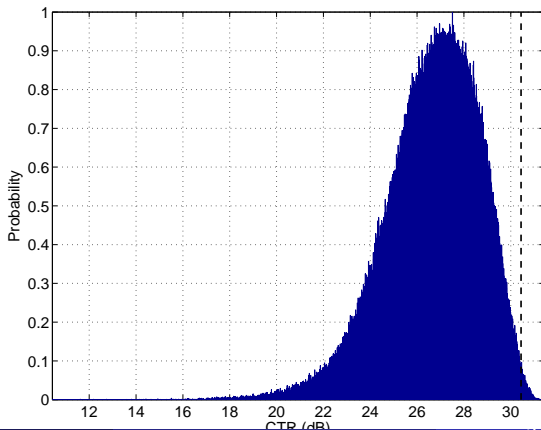
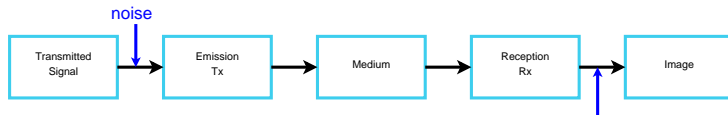
Results for linear system

Results for linear system



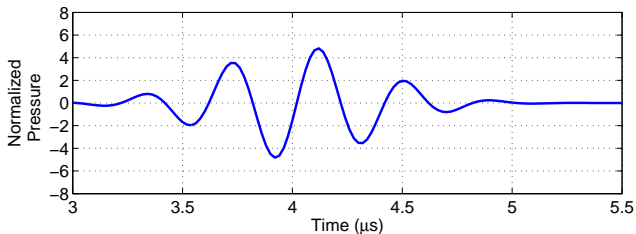
Results for nonlinear pulse inversion imaging system

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Results for nonlinear pulse inversion imaging system

Results for nonlinear pulse inversion imaging system



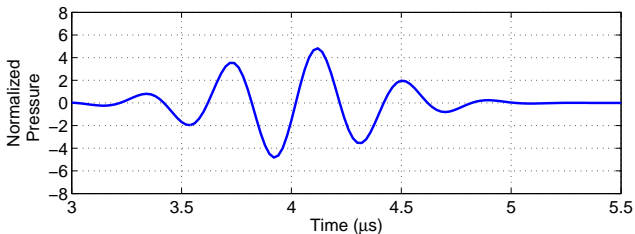
$$f_{opt} = 2.5 \text{ MHz}$$

$$CTR = 30.4 \text{ dB}$$

(Ménigot, 2009)

Results for nonlinear pulse inversion imaging system

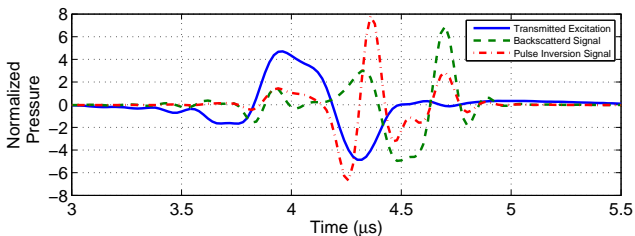
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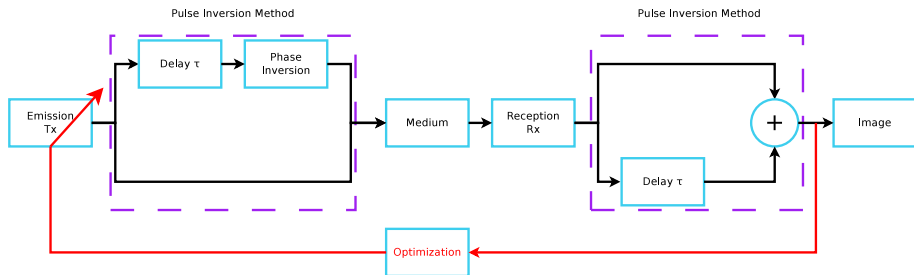
$$CTR = 31.4 \text{ dB}$$

1 million of tests

Parametric Optimization

Implementation

Implementation of the Parametric Optimization

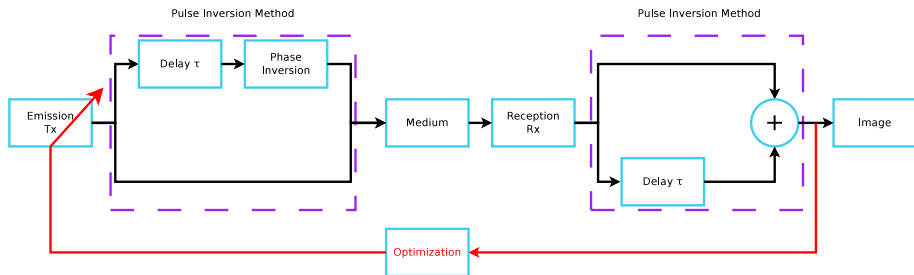


Setting of Iterative Optimization

- ① Choice of the Cost Function $J(\theta)$
- ② Choice of the parameters θ
- ③ Choice of the optimization algorithm

Implementation

Implementation of the Parametric Optimization

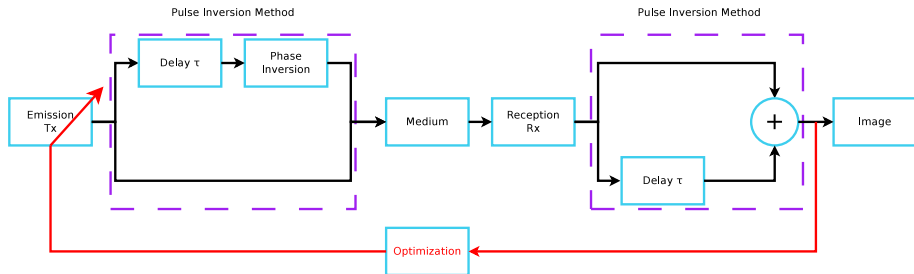


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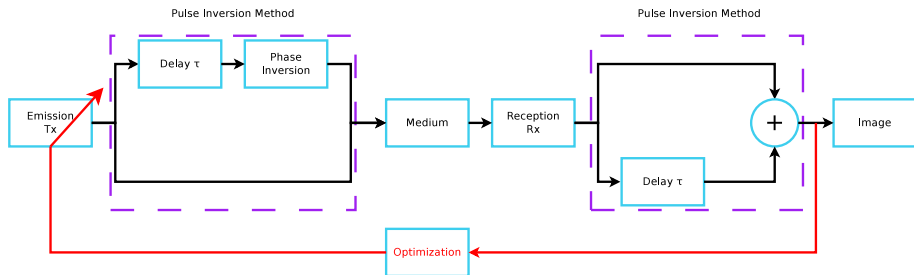


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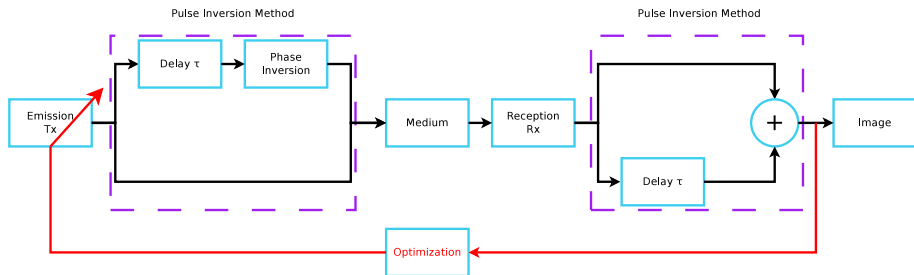


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Implementation of the Parametric Optimization



Setting of Iterative Optimization

- 1 Choice of the Cost Function $J(\theta) \rightarrow CTR$
- 2 Choice of the parameters θ
- 3 Choice of the optimization algorithm

Implementation of the Parametric Optimization

Optimization Setting

- 1 Maximization of the *CTR*
- 2 Input signal described by autoregressive model

$$\hat{x}(t) = \sum_{i=0}^{M-1} h_1(i)x(t-i)$$

- 3 Nelder-Mead's Algorithm based on simplex

Implementation of the Parametric Optimization

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Implementation of the Parametric Optimization

Optimization Setting

- 1 Maximization of the *CTR*
- 2 Input signal described by nonlinear autoregressive model (NAR)

$$\hat{x}(t) = \sum_{i=0}^{M-1} h_1(i)x(t-i) + \sum_{i=0}^{M-1} \sum_{j=i}^M h_2(i,j)x(t-i)x(t-j) + \dots$$

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Implementation of the Parametric Optimization

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- 1 Maximization of the *CTR*
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Order $K = 3$ and memory $M = 3 \Rightarrow$ **19 parameters**

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Order $K = 3$ and memory $M = 3 \Rightarrow 19$ parameters

Drawback: what is the signal $x(t)$?

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\Rightarrow **Optimal Input Signal obtained randomly**

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Results with Parametric Optimization

	Pulse $f_{opt} = 2.5$ MHz	Random	Random with Parametric Optimization
<i>CTR</i>	30.4 dB	31.4 dB	

Results with Parametric Optimization

Pulse
 $f_{opt} = 2.5$ MHz

Random

Random with
 Parametric
 Optimization

CTR

30.4 dB

31.4 dB

31.5 dB

Results with Parametric Optimization

	Pulse $f_{opt} = 2.5$ MHz	Random	Random with Parametric Optimization
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<i>CTR</i>	30.4 dB	31.4 dB	31.5 dB
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Comparison

	Pulse $f_{opt} = 2.5$ MHz	Random	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	
N_{test}	-	15	

Comparison

	Pulse $f_{opt} = 2.5$ MHz	Random	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	31.3 dB
N_{test}	-	15	2165

Comparison

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N_{test}	-	15	258

Comparison

	Pulse $f_{opt} = 2.5$ MHz	Random	Random	Random with Parametric Optimization
<i>CTR</i>	30.4 dB	30.5 dB	31.3 dB	31.3 dB
N_{test}	-	15	2165	258

Conclusion & Prospects

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- Random process without *a priori* knowledge of the medium
- Decrease test number by combination between random process and parametric optimization
- Prospects:
 - Analysis the optimal excitation
 - Find the optimal command by metaheuristic
 - In NDE, test number is not a problem

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Thank you for your attention

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Institut national
de la santé et de la recherche médicale