Anonymity test attacks and vulnerability indicators for the “Patient characteristics” disclosure in medical articles

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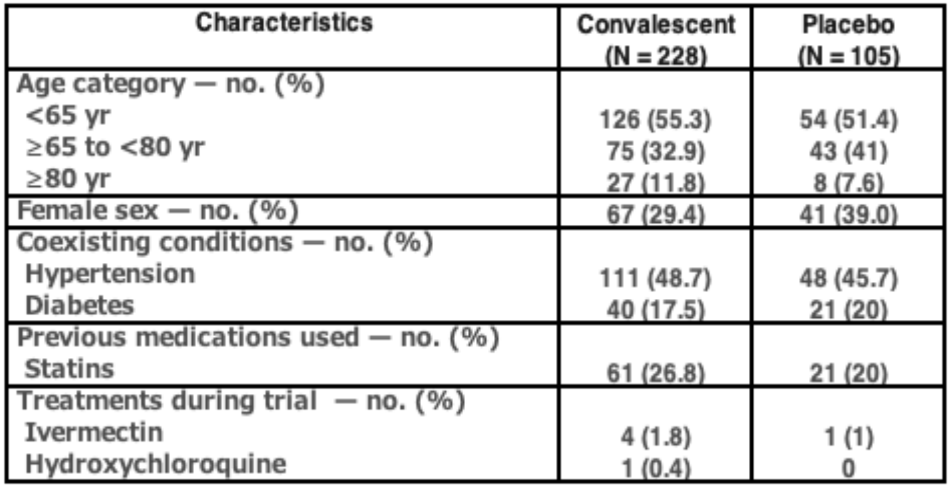
Overview of Presentation
Proposal attacks on Patient characteristics

① Patient characteristics



Characteristics	Convalescent (N = 228)	Placebo (N = 105)
Age category — no. (%)		
<65 yr	126 (55.3)	54 (51.4)
≥65 to <80 yr	75 (32.9)	43 (41)
≥80 yr	27 (11.8)	8 (7.6)
Female sex — no. (%)	67 (29.4)	41 (39.0)
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Hypertension	111 (48.7)	48 (45.7)
Diabetes	40 (17.5)	21 (20)
Previous medications used — no. (%)		
Statins	61 (26.8)	21 (20)
Treatments during trial — no. (%)		
Ivermectin	4 (1.8)	1 (1)
Hydroxychloroquine	1 (0.4)	0

(V. A. Simonovich, et al., New England Journal of Medicine, 2021.)

② 3 Proposal Anonymity invasion Attacks
= Attack Success
means Privacy Risk

③ 3 Proposal Indicators
By l-diversity concept
= Quantitative Anonymity Indicators
for Patient characteristics

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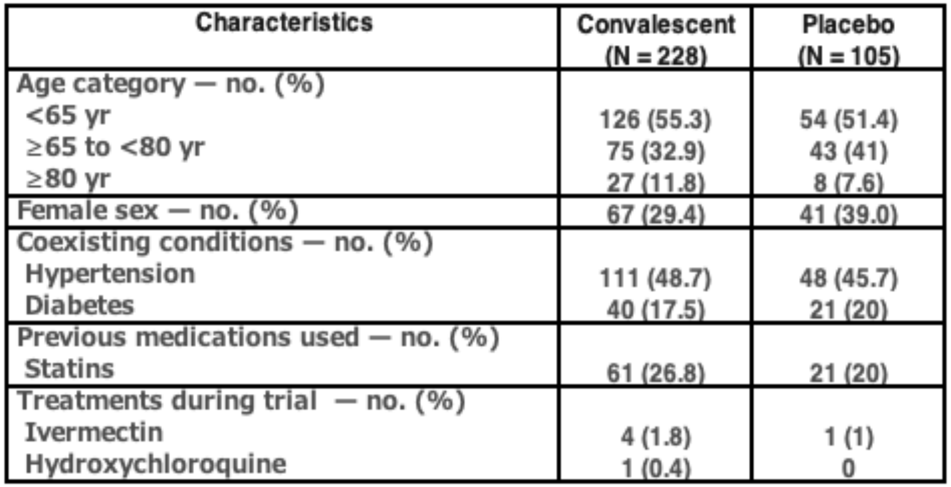

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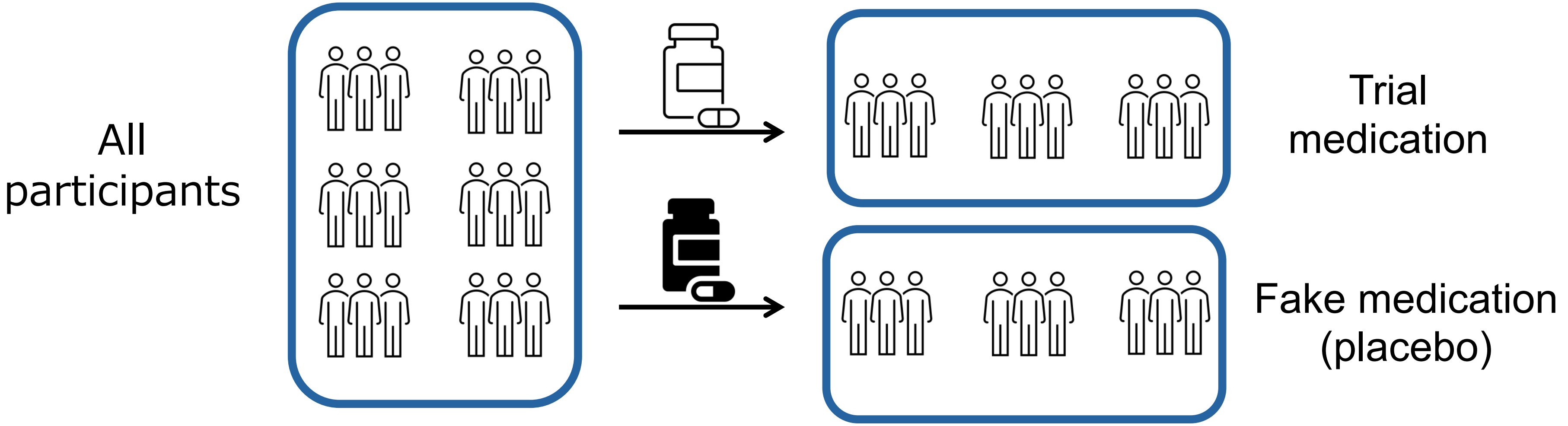
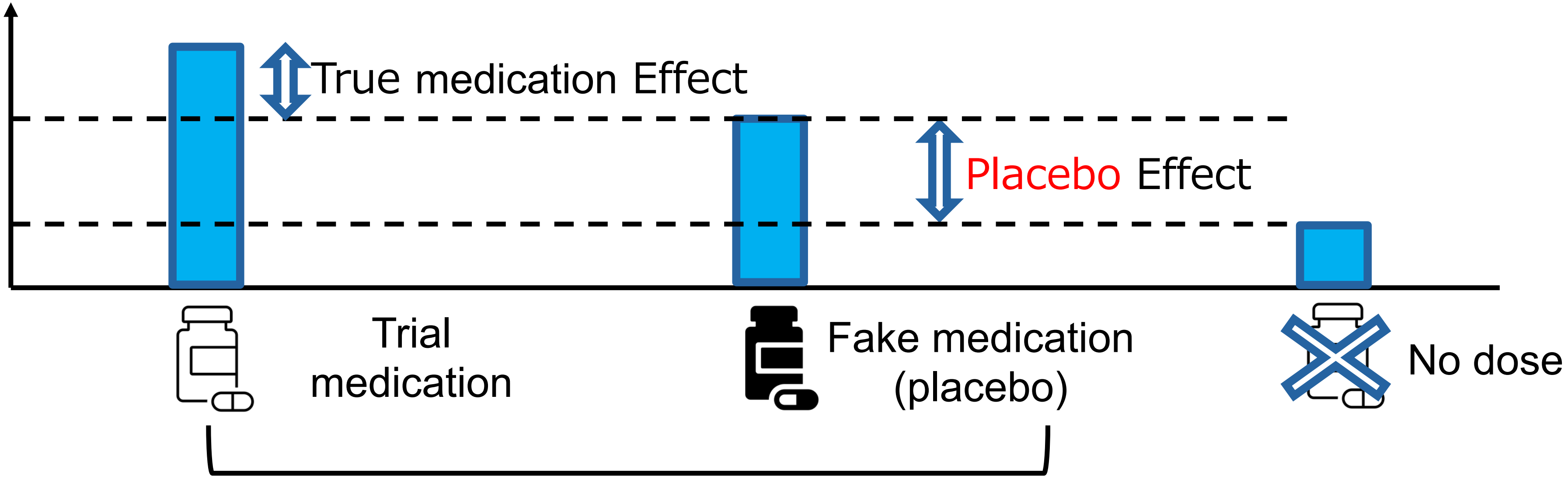
Background Placebo effect



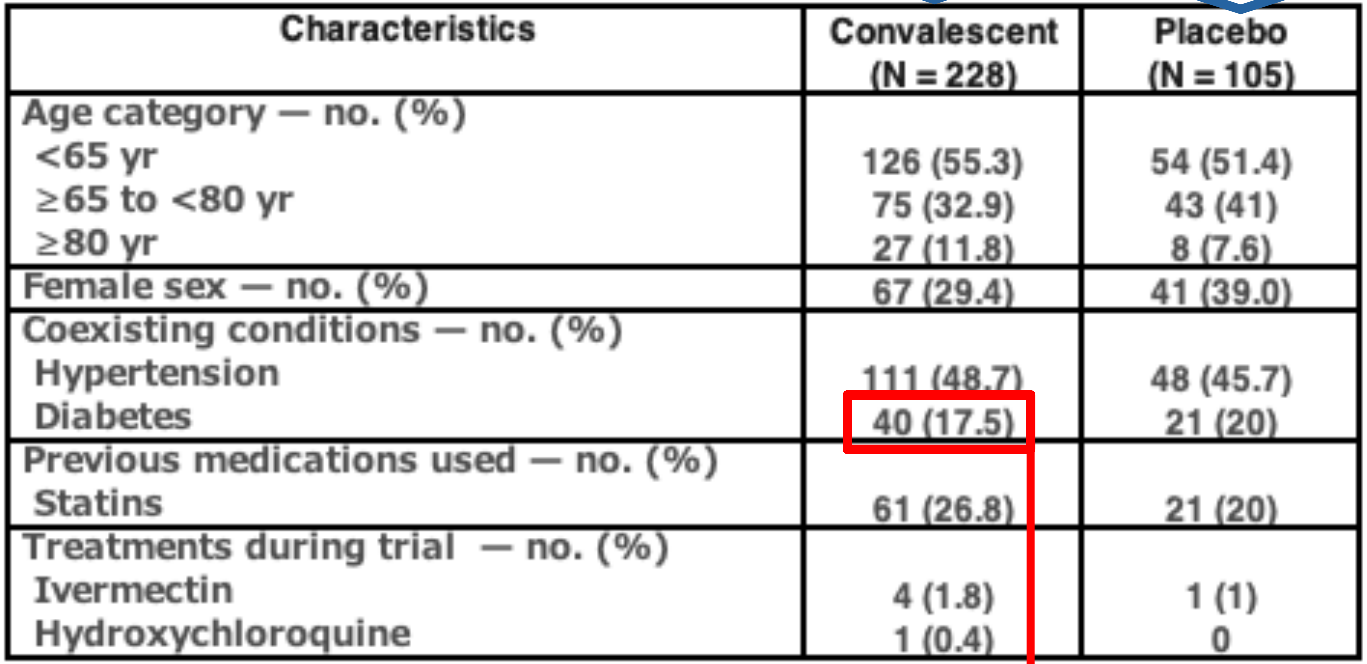


Double-blind: both the patient and the medical doctor are unsure whether the medication is a trial medication or a fake.

Background Patient characteristics

Trial medication

Fake medication (placebo)



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Anonymous?

Statical information ⇨ Unknown whether a particular clinical participant is diabetic or not.

Research objective: Check the anonymity of patient characteristics

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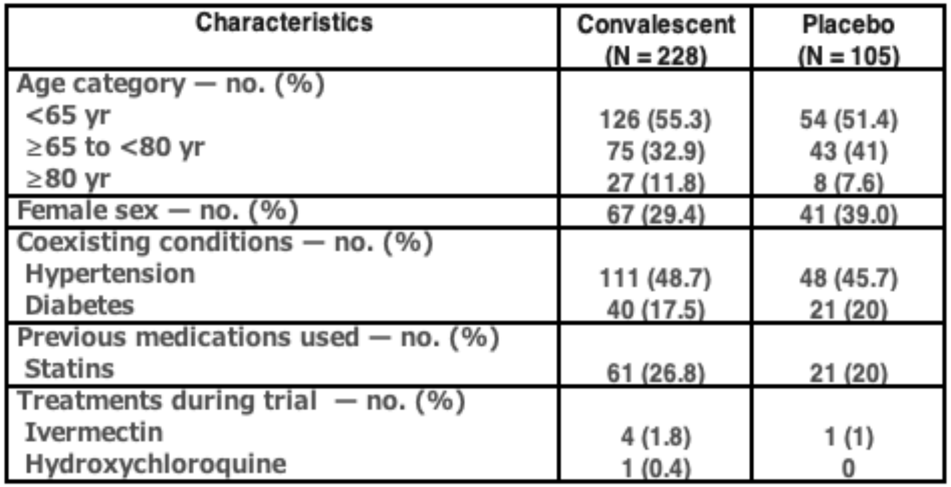
Background

① Patient characteristics



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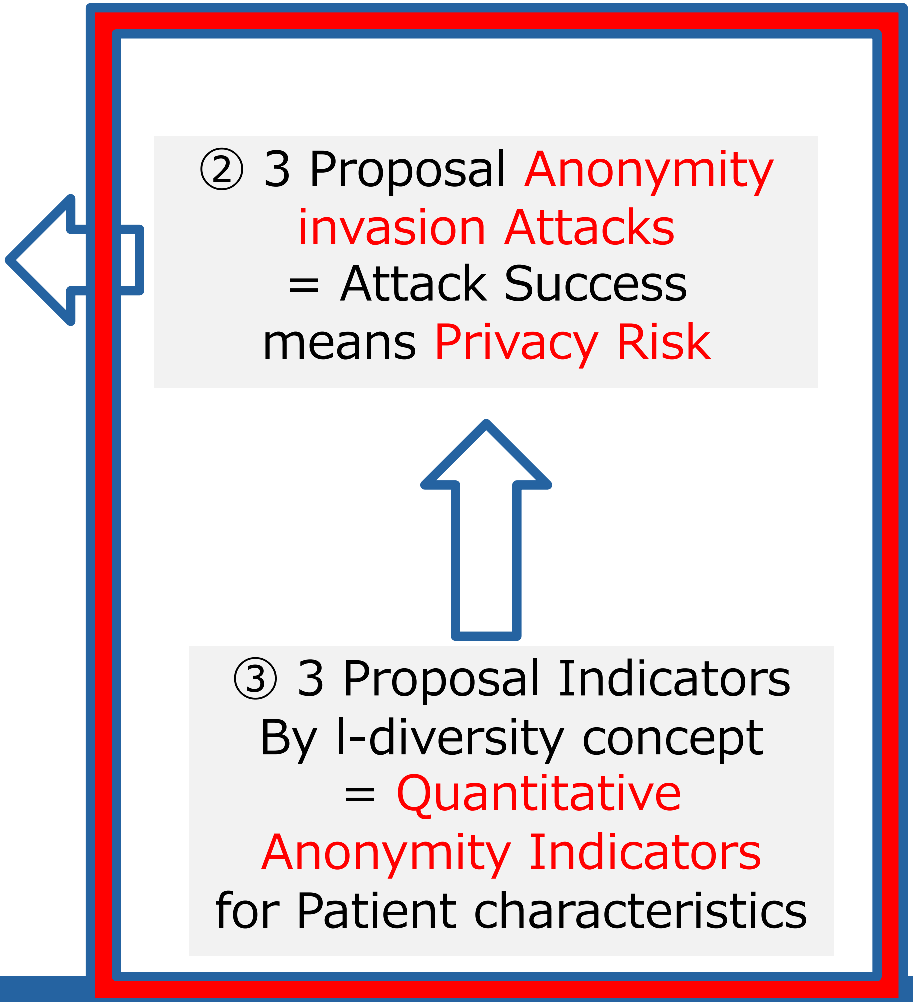

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Background PPDP

- Privacy-Preserving Data Publishing (PPDP)
    - Data disclosure with privacy protection

Examples of Disclosure
Census, Kaggle, competitions, etc.

Gender	Age	Occupation	Annual Income
Male	20s	F&B	50K $
Male	40s	F&B	60K $
Female	30s	Finance	20K $
Female	50s	Medicine	30K $

Tradeoff：Availability vs. Anonymity

(B. C. M. Fung, *et al.*, ACM Computing Surveys, 2010.)

Background PPDP's Anonymity Indicators and Privacy Invasion Attacks

- PPDP's anonymity indicator = Assuming an attack and measuring the percentage of attack protection (C. Dwork, et al., Annual Re- view of Statistics and Its Application, 2017.)

Gender	Age	Occupation	Annual Income
Male	20s	Cafe	80K $
Male	30s	Izakaya	100K $
Female	50s	Noodle shop	50K $
Female	20s	Bakery	40K $
Male	40s	Bank	70K $
Male	30s	Insurance	60K $
Female	20s	Securities	40K $
Female	50s	Accounting	90K $

Disclosure Information

Name	Gender	Age	Occupation
Alice	Female	20s	Finance

Attacker’s Supplemental information

Link attack: attacker finds out that Alice's annual income is 40K $

Background Link Attack Resistance by k-Anonymization 、 Privacy invasion attacks on k-anonymized information

Gender	Age	Occupation	Annual Income
Male	20s	Cafe	80K $
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Female	50s	Accounting	90K $

k-Anonymization

Gender	Age	Occupation	Annual Income
Male	20-50s	F&B	80K $
Male	20-50s	F&B	100K $
Female	20-50s	F&B	50K $
Female	20-50s	F&B	40K $
Male	20-50s	Finance	70K $
Male	20-50s	Finance	60K $
Female	20-50s	Finance	40K $
Female	20-50s	Finance	90K $

Attacker's Supplemental information

Name	Gender	Age	Occupation
Alice	Female	20s	Finance
Bob	Male	30s	F&B

- **Homogeneous attack: F&B man earns over 8milion**

A. Machanava jjhala, et al., ACM Transactions on Knowledge Discovery from Data (TKDD), 2007.

Background Homogeneous Attack Resistant l-Diversity Data

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⇨ l-Diversity

Gender	Age	Occupation	Annual Income
Male	20-50s	F&B or Finance	60K $
Male	20-50s	F&B or Finance	70K $
Male	20-50s	F&B or Finance	80K $
Male	20-50s	F&B or Finance	100K $
Female	20-50s	F&B or Finance	40K $
Female	20-50s	F&B or Finance	60K $
Female	20-50s	F&B or Finance	70K $
Female	20-50s	F&B or Finance	90K $

Attacker’s Supplemental information

Name	Gender	Age	Occupation
Alice	Female	20s	Finance
Bob	Male	30s	F&B

- Homogeneous Attack ⇨ Bob's annual income cannot be determined to be more than 80K$

Background: Indicator of l-diversity

	Gender	Age	Occupation	Annual Income
q* 1	Male	20-50s	F&B or Finance	60K $
	Male	20-50s	F&B or Finance	70K $
	Male	20-50s	F&B or Finance	80K $
	Male	20-50s	F&B or Finance	100K $
q* 2	Female	20-50s	F&B or Finance	40K $
	Female	20-50s	F&B or Finance	90K $
	Female	20-50s	F&B or Finance	60K $
	Female	20-50s	F&B or Finance	70K $

- Quantitative evaluation indicator of l-diversity :
  - Entropy l-Diversity

$$-\sum_{s \in S} p(q*, s) \log(p(q*, s)) \geqq \log(l)$$

q*1 = {Male, 20-50s, F & B or Finance}, S = {60K $, 70K $, 80K $, 100K $}, p(q1*, s) = ¼ ⇨ left side = - (1/4 log(1/4))*4 = log 4

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Proposal attacks on Patient characteristics

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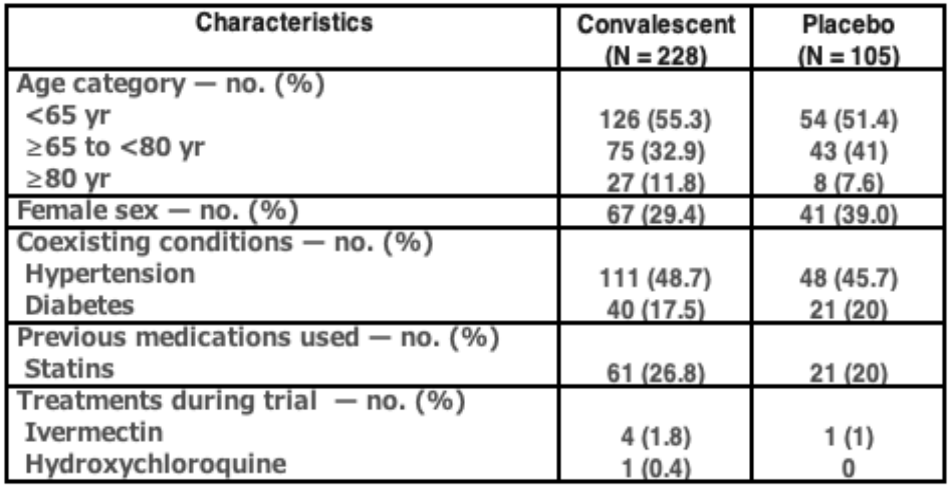

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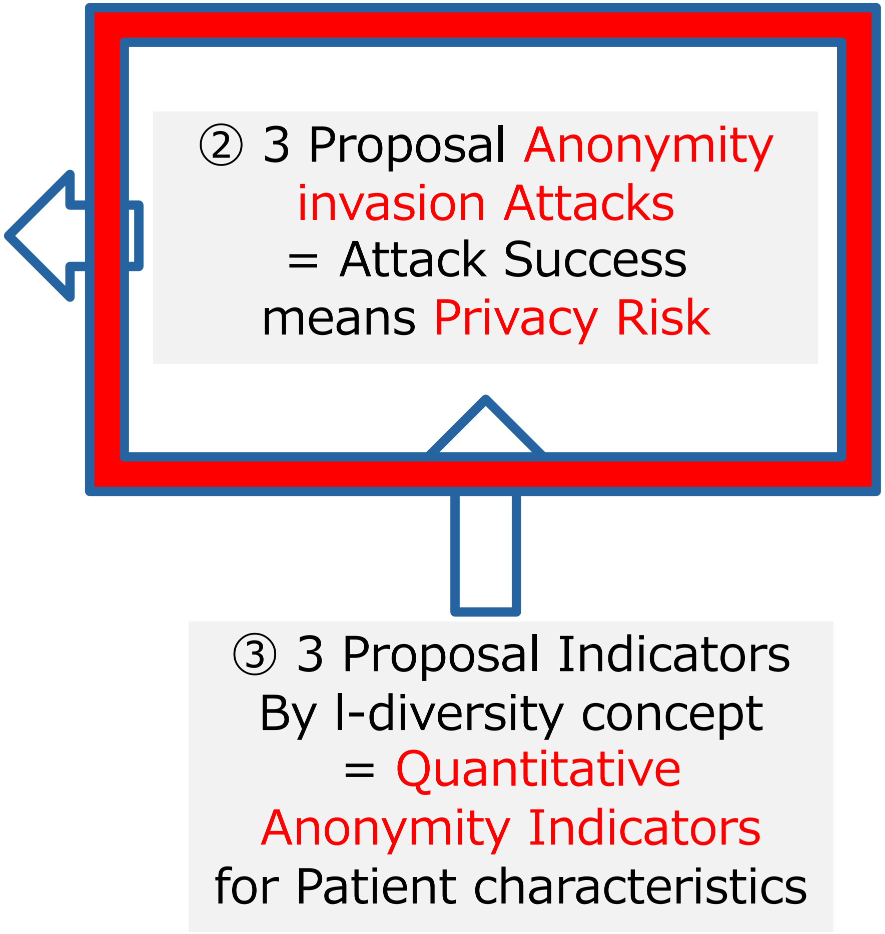

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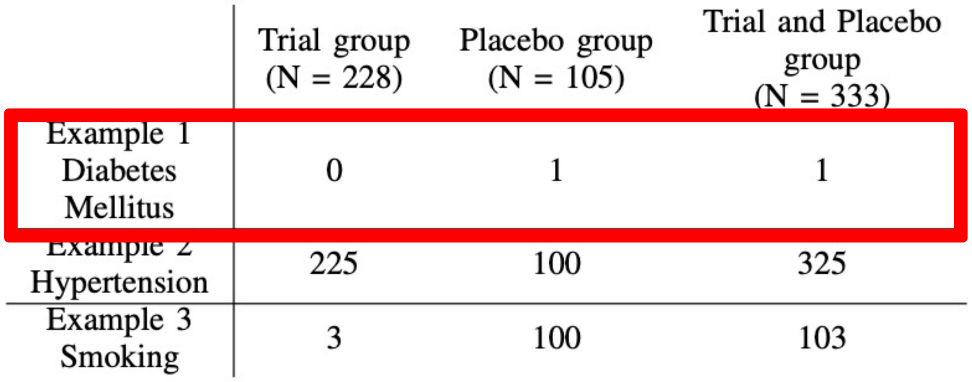
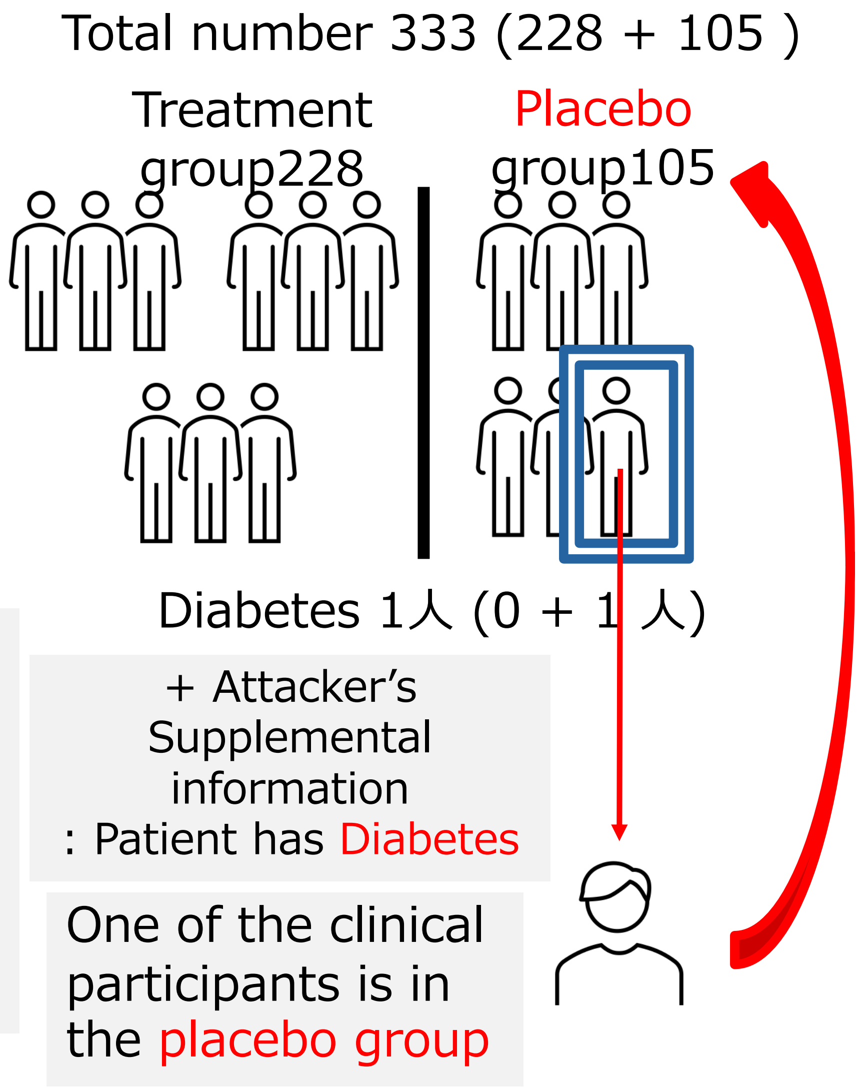
Attack 1 Patient Detect Placebo (PDP) attack



	Trial group (N = 228)	Placebo group (N = 105)	Trial and Placebo group (N = 333)
Example 1 Diabetes Mellitus	0	1	1
Example 2 Hypertension	225	100	325
Example 3 Smoking	3	100	103

- Attacker: Patient him/herself
- PDP attack: Estimate whether patients in a clinical trial are in the treatment or placebo group = double-blind is broken



Total number 333 (228 + 105)

Treatment group228

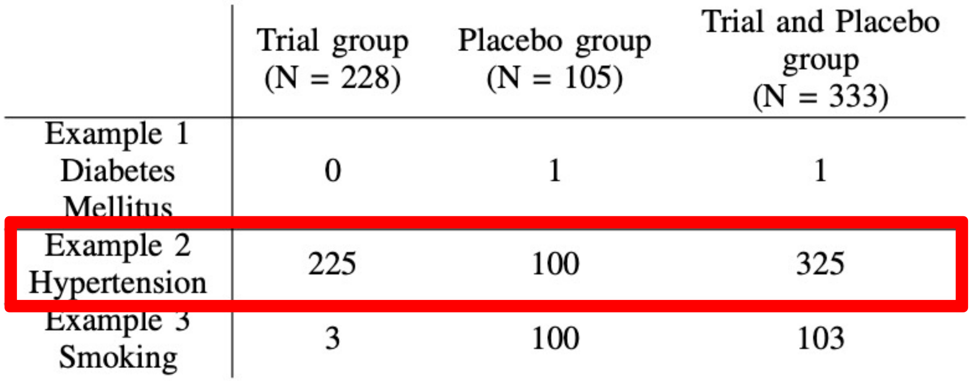
Placebo group105

Diabetes 1人 (0 + 1 人)

+ Attacker's Supplemental information : Patient has Diabetes

One of the clinical participants is in the placebo group

Attack 2 Patient Family Detect on Overall Category (PFDOC) attack



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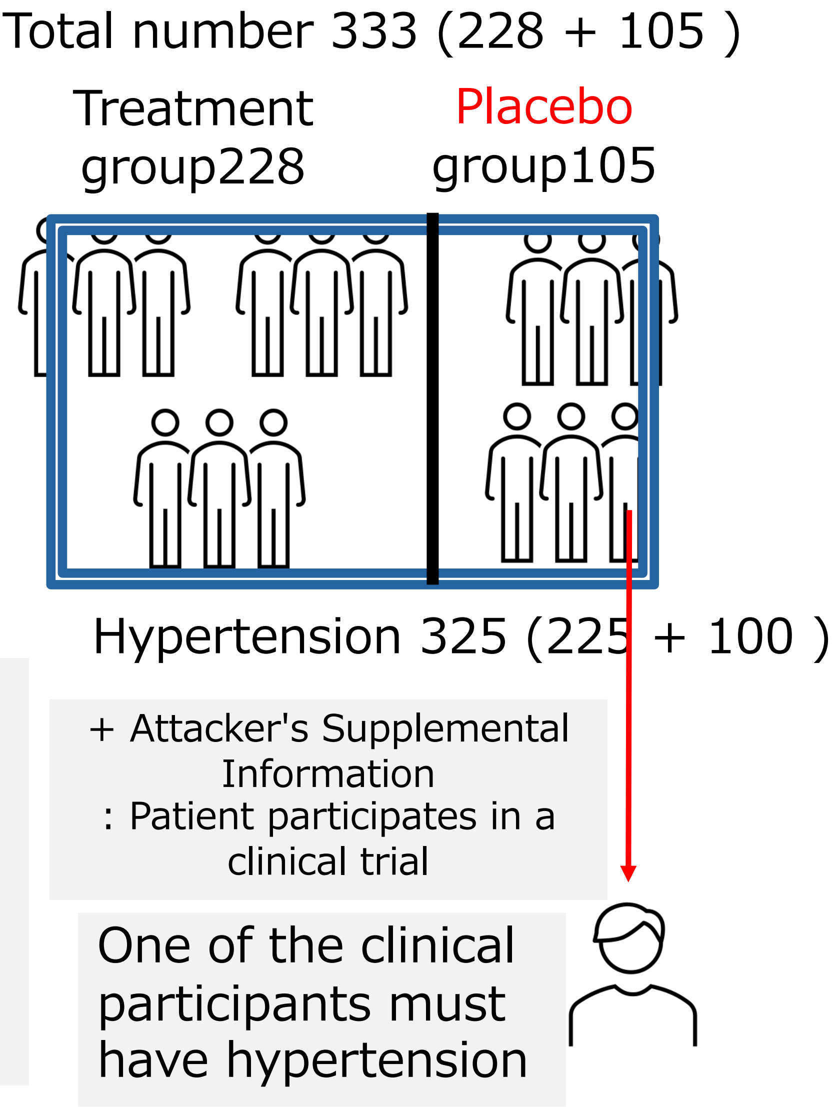
- Attacker: Patient's family
- PFDOC attack: Estimate whether a patient belongs to a category = leakage of sensitive information



Total number 333 (228 + 105)

Treatment group228

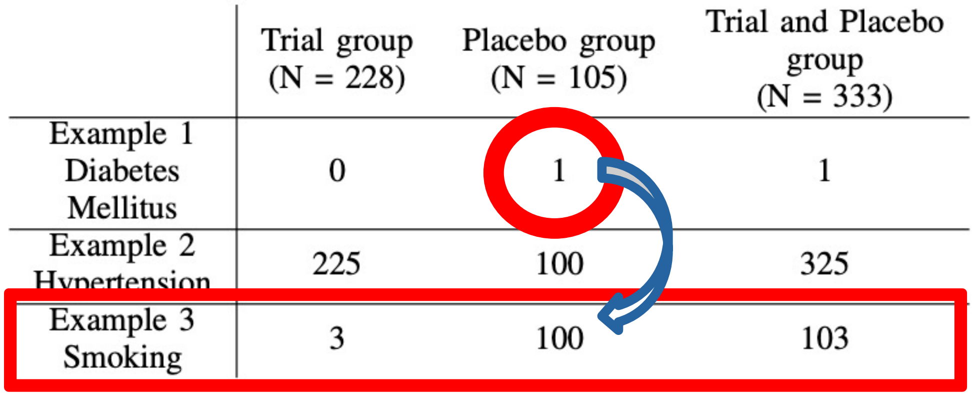
Placebo group105

Hypertension 325 (225 + 100)

+ Attacker's Supplemental Information
: Patient participates in a clinical trial

One of the clinical participants must have hypertension

Attack3 Patient Family Detect on Placebo and Treatment Category (PFDPTC) attack



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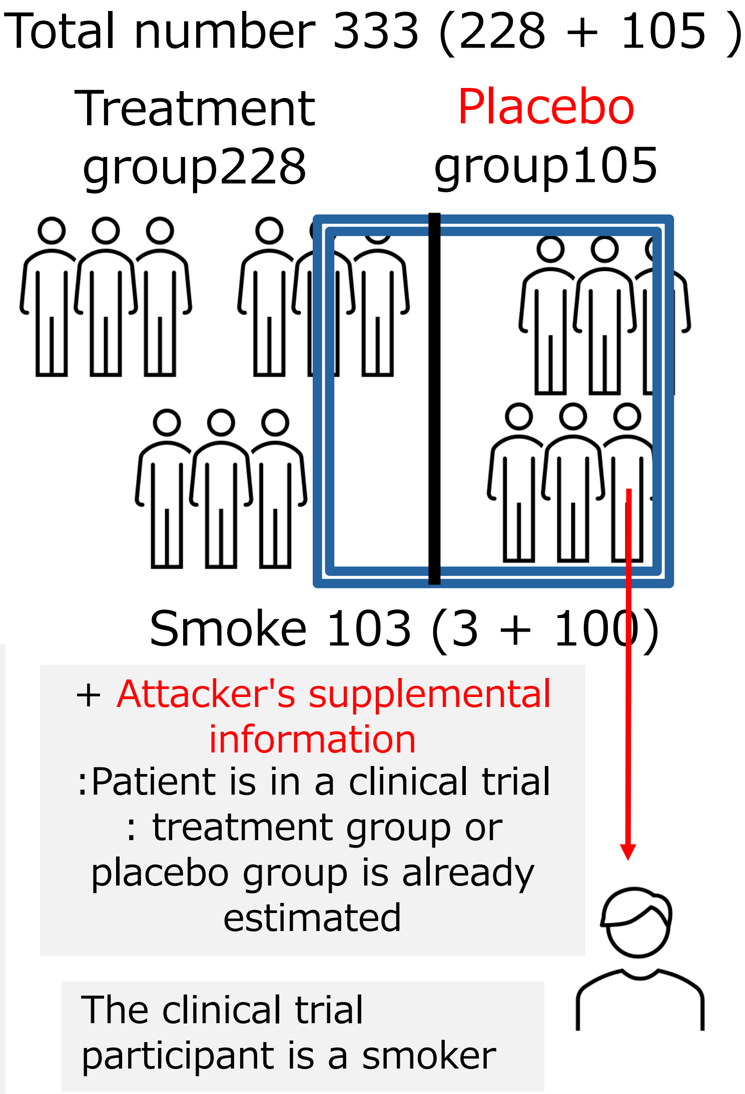
- Attacker: Patient's family
- PFDPTC attack: After estimating whether a patient belongs to the treatment group or the placebo group, the attacker estimates whether the patient belongs to the category or not = leakage of sensitive information



+ Attacker's supplemental information
:Patient is in a clinical trial
: treatment group or placebo group is already estimated

The clinical trial participant is a smoker

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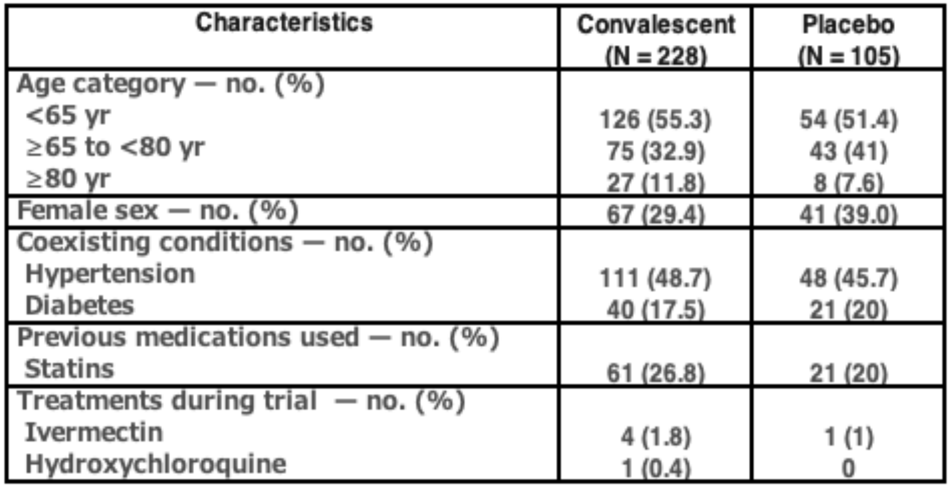

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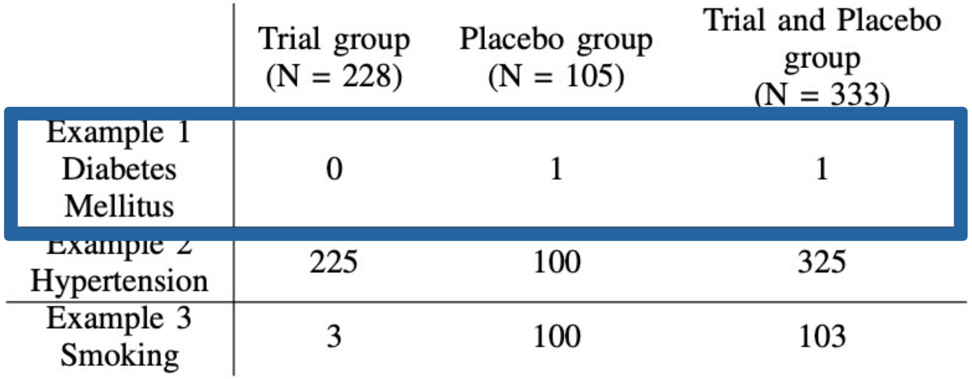
Proposal indicator 1 for PDP Attack indicator



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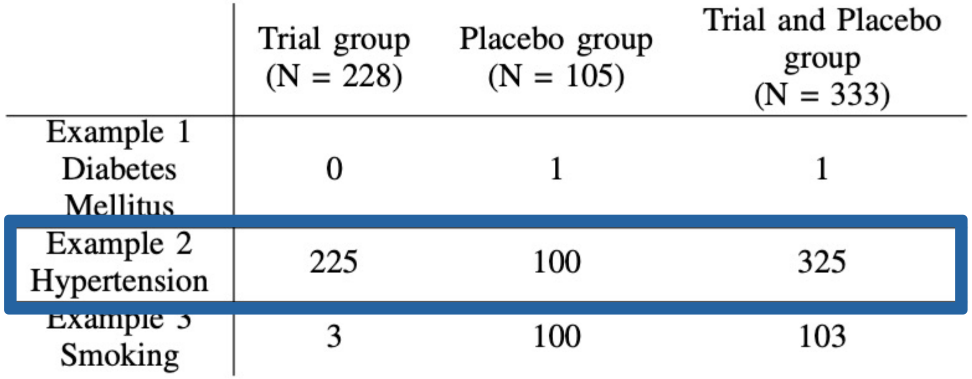
	Treatment group (Na)	Placebo group (Nb)	Treatment group + Placebo group (Nc = Na + Nb)
category	A	B	C = A + B

- Bias in Trial group vs. placebo group is problematic
- PDP Entropy
  - − (A/(A + B)) log(A/(A + B))− (B/(A + B)) log(B/(A + B))

(※ entropy = 0 when A = 0 or B = 0)

- PDP Entropy l-Diversity
  - PDP Entropy ≧ log (l)

Proposal indicator 2 for PFDOC Attack



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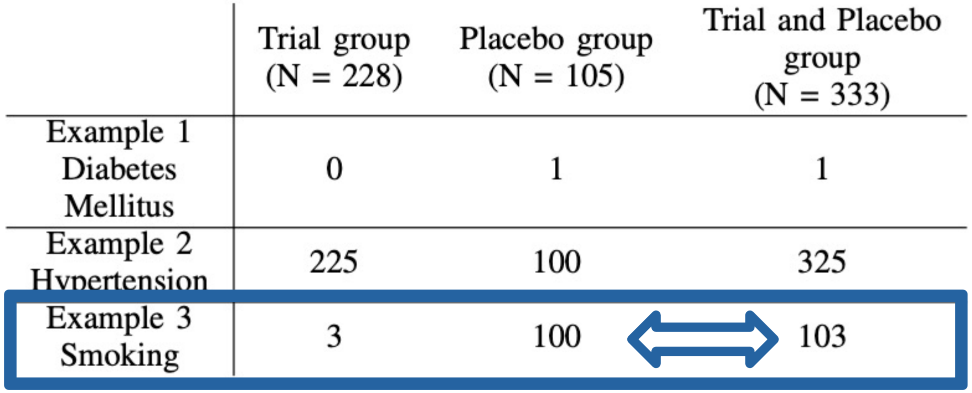
- Bias in “Trial group + Placebo group” vs “Total participants” number is problematic
- PFDOC entropy
  - − (C/Nc) log(C/Nc) − ((N c − C)/N c)) log((N c − C)/N c)) (※ entropy = 0 when C = 0)
- PFDOC entropy l-Diversity
  - PFDOC entropy ≧ log (l)

Proposal indicator 3 for PFDPTC Attack



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category	A	B	C = A + B

- Bias in “Trial + Placebo" vs. ”Trial or Placebo" is problematic
- PFDPTC entropy
  - - (A/Na) log(A/Na) - ((Na – A)/Na) log((Na – A)/ Na) ⇦Estimated treatment group
  - - (B/Nb) log(B/Nb) - ((Nb – B)/Nb) log ((Nb – B)/ Nb) ⇦Estimated placebo group

  (※ entropy = 0 when A = 0 or B = 0)
- PFDPTC differential entropy
  - PFDPTC differential entropy

  = |PFDPTC entropy – PFDOC entropy|

  (※PFDOC entropy = – (C/Nc) log(C/Nc) – ((N c – C)/N c)) log((N c – C)/N c)))
- PFDPTC differential entropy l-Diversity
  - PFDPTC differential entropy ≦ log (l)

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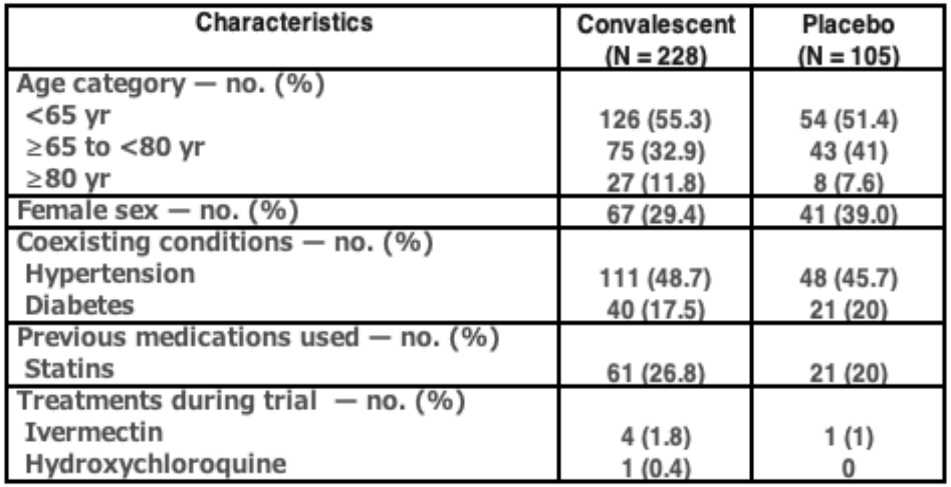

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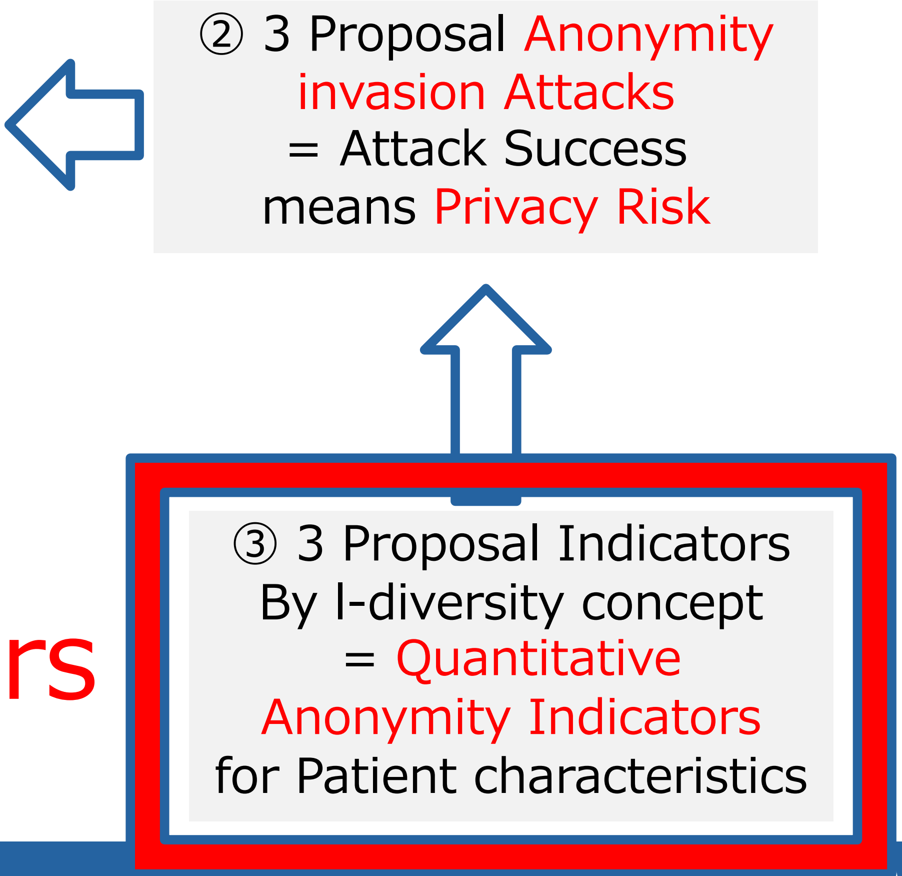

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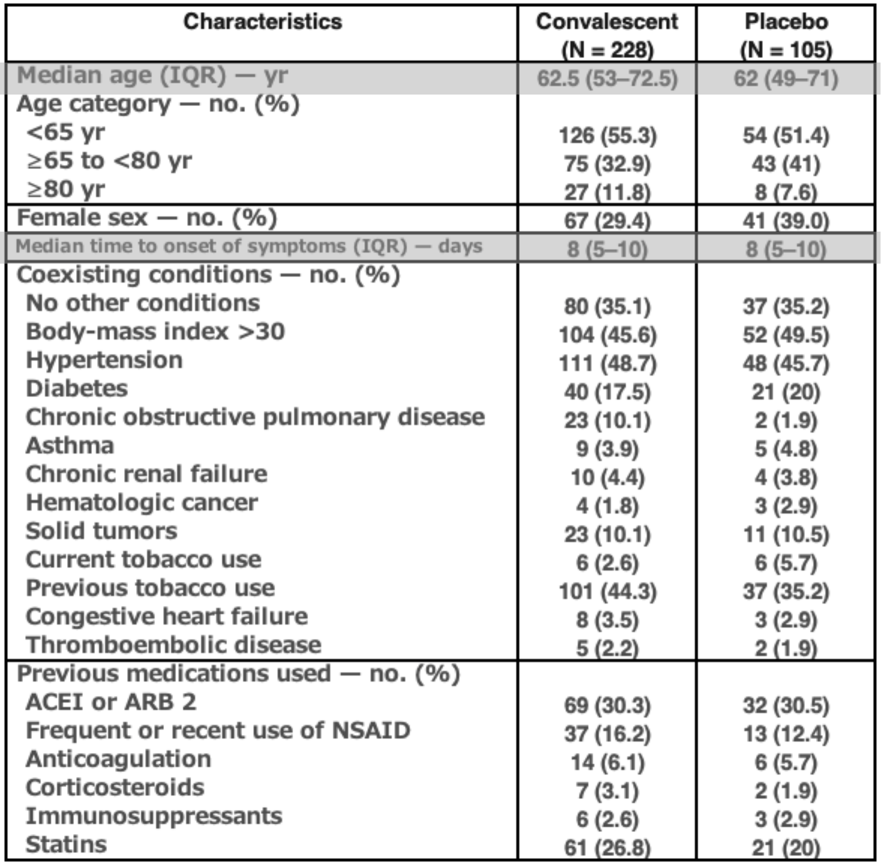
Test the Indicators on Real data

Material



Characteristics	Convalescent (N = 228)	Placebo (N = 105)
Median age (IQR) — yr	62.5 (53–72.5)	62 (49–71)
Age category — no. (%)		
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≥65 to <80 yr	75 (32.9)	43 (41)
≥80 yr	27 (11.8)	8 (7.6)
Female sex — no. (%)	67 (29.4)	41 (39.0)
Median time to onset of symptoms (IQR) — days	8 (5–10)	8 (5–10)
Coexisting conditions — no. (%)		
No other conditions	80 (35.1)	37 (35.2)
Body-mass index >30	104 (45.6)	52 (49.5)
Hypertension	111 (48.7)	48 (45.7)
Diabetes	40 (17.5)	21 (20)
Chronic obstructive pulmonary disease	23 (10.1)	2 (1.9)
Asthma	9 (3.9)	5 (4.8)
Chronic renal failure	10 (4.4)	4 (3.8)
Hematologic cancer	4 (1.8)	3 (2.9)
Solid tumors	23 (10.1)	11 (10.5)
Current tobacco use	6 (2.6)	6 (5.7)
Previous tobacco use	101 (44.3)	37 (35.2)
Congestive heart failure	8 (3.5)	3 (2.9)
Thromboembolic disease	5 (2.2)	2 (1.9)
Previous medications used — no. (%)		
ACEI or ARB 2	69 (30.3)	32 (30.5)
Frequent or recent use of NSAID	37 (16.2)	13 (12.4)
Anticoagulation	14 (6.1)	6 (5.7)
Corticosteroids	7 (3.1)	2 (1.9)
Immunosuppressants	6 (2.6)	3 (2.9)
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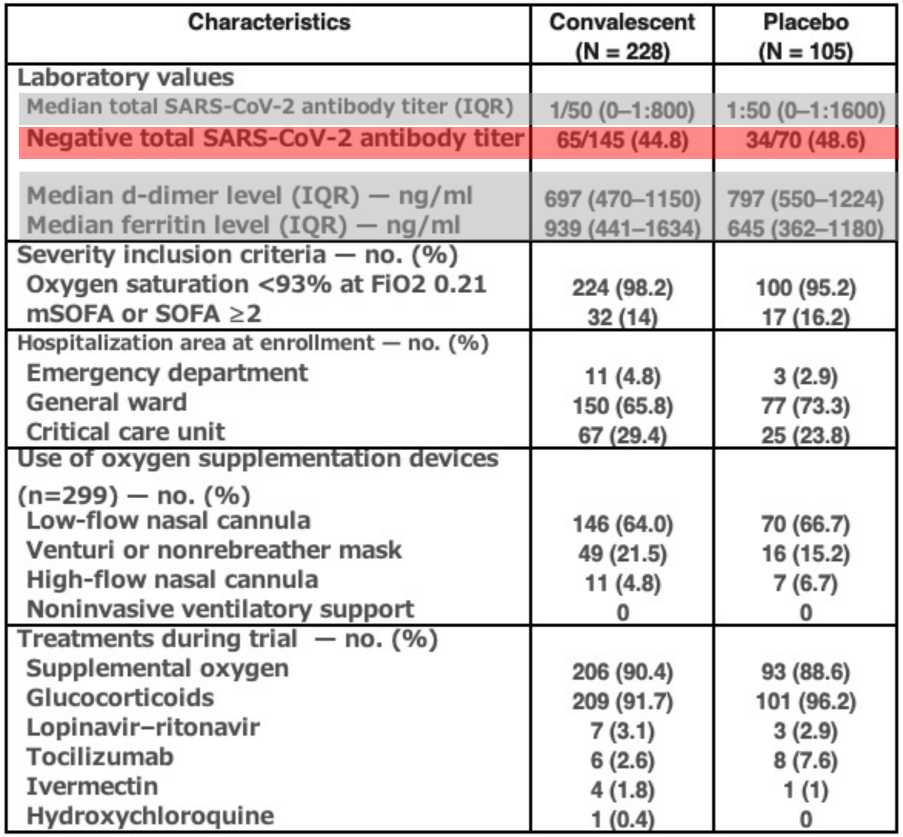


Characteristics	Convalescent (N = 228)	Placebo (N = 105)
Laboratory values		
Median total SARS-CoV-2 antibody titer (IQR)	1/50 (0–1:800)	1:50 (0–1:1600)
Negative total SARS-CoV-2 antibody titer	65/145 (44.8)	34/70 (48.6)
Median d-dimer level (IQR) — ng/ml	697 (470–1150)	797 (550–1224)
Median ferritin level (IQR) — ng/ml	939 (441–1634)	645 (362–1180)
Severity inclusion criteria — no. (%)		
Oxygen saturation <93% at FiO2 0.21	224 (98.2)	100 (95.2)
mSOFA or SOFA ≥2	32 (14)	17 (16.2)
Hospitalization area at enrollment — no. (%)		
Emergency department	11 (4.8)	3 (2.9)
General ward	150 (65.8)	77 (73.3)
Critical care unit	67 (29.4)	25 (23.8)
Use of oxygen supplementation devices (n=299) — no. (%)		
Low-flow nasal cannula	146 (64.0)	70 (66.7)
Venturi or nonrebreather mask	49 (21.5)	16 (15.2)
High-flow nasal cannula	11 (4.8)	7 (6.7)
Noninvasive ventilatory support	0	0
Treatments during trial — no. (%)		
Supplemental oxygen	206 (90.4)	93 (88.6)
Glucocorticoids	209 (91.7)	101 (96.2)
Lopinavir–ritonavir	7 (3.1)	3 (2.9)
Tocilizumab	6 (2.6)	8 (7.6)
Ivermectin	4 (1.8)	1 (1)
Hydroxychloroquine	1 (0.4)	0

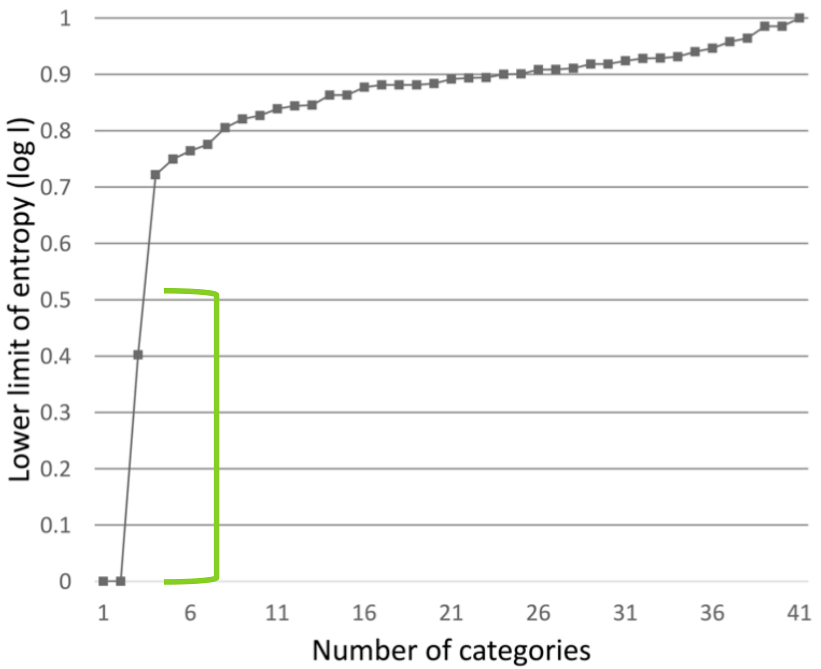
(V. A. Simonovich, et al., New England Journal of Medicine, 2021.)

※ Treatment group : Placebo group = 2 : 1 Number of allocation

※ Negative total SARS- CoV-2 antibody titer — no./total no. (%)

⇨Analyzed by {No sampling, Sampling & Negative, Sampling & Positive}

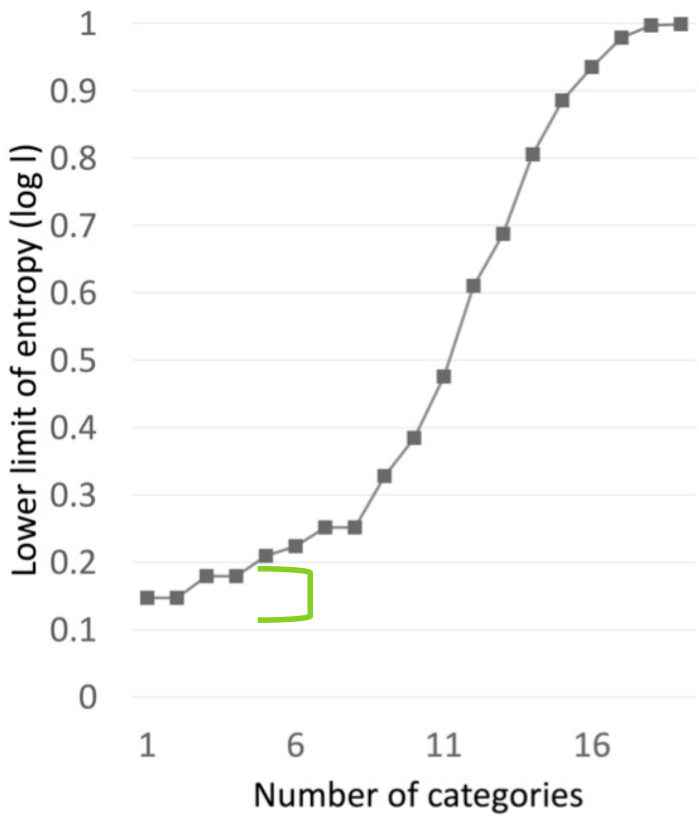
Result PDP attack



	Trial group	Placebo group	log(l)
Noninvasive ventilatory support	0	0	0
Hydroxychloroquine	1	0	0
Chronic obstructive pulmonary disease	23	2	0.402

PDP entropy to preserve all categories l-diversity: l = 1

Result PFDOC attack



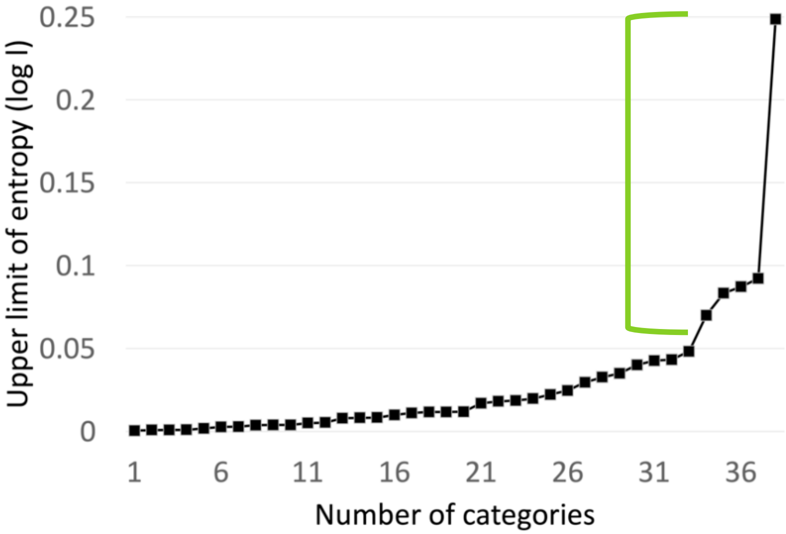
	Treatment group + Placebo group	log(l)
Hematologic cancer	7	0.147
Thromboembolic disease	7	0.147
Corticosteroids	9	0.179
Immunosuppressants	9	0.179

PFDOC entropy was low because of the "low probability" category.

⇨The categories were not confirmed disease name

PFDOC entropy to preserve all categories l-diversity : l = 1.107.

Result PFDPTC attack



Category	Trial group (228)	Placebo group (105)	Trial group + Placebo group (333)	log(l)
Frequent or recent use of NSAID		15 14%	82 25%	0.0700
Statins		21 20%	82 25%	0.0833
Chronic obstructive pulmonary disease	23 10.1%		25 7.5%	0.0872
Current tobacco use		6 5.7%	12 3.6%	0.0922
Chronic obstructive pulmonary disease		2 1.9%	25 7.5%	0.2485

PFDPTC Difference Entropy to preserve all categories l-Diversity : l = 1.188

Discussion

	Result of Attack on Patient characteristics	I	Quantitative Anonymity Assessment Function (= vulnerability detection potential)
PDP Attack	✔ Mainly, patients are noted as being in the treatment group	< 1	✔ Indicators of Blindness = Potential patient health hazard
PFDOC Attack	△ Mainly, patients do not "belong" to a category	< 1.107	△ Medical evidence becomes a "correlation" as a general statement.(C. Dwork, et al., Annual Re- view of Statistics and Its Application, 2017.) ⇨ Possible non-invasion of privacy
PFDPTC Attack	✔ Mainly, patients' probability of belonging to a category changes from the probability known from the "treatment + placebo" group.	> 1.188	✔ Indicators of privacy invasion = Leakage of sensitive information

Summary

- A quantitative anonymity indicator applying l-diversity is proposed for the three attacks.
- We evaluated the anonymity indicator in specific patient characteristics and confirmed the ability.

- Future work: There are various forms of patient characteristics in research methods such as scoring studies and case reports, and we propose anonymity indices for each of these forms.