ISCI INSTITUTO SISTEMAS COMPLEJOS DE INGENIERÍA COVID-19

June 2020
Santiago, Chile.

# Optimizing the care capacity of critical intensive care personnel

Complex Engineering Systems Institute (ISCI)

Industrial Engineering, FCFM – Universidad de Chile.

# THE PROBLEM

The COVID-19 pandemic has created a challenge of unprecedented proportions for which an optimal operation of Intensive Care beds is paramount.

The availability of beds and respirators is relevant, but just as important is the availability of medical personnel trained in their operation and the providing of adequate treatment to patients.

Facing a global scarcity of personal protective equipment (PPE) and a high flow of patients, high rates of infection have been shown among medical staff in countries such as Italy, Spain, and the USA, which has a significant negative impact on care, in particular to those in a critical condition.

Chile is no exception…

CRITICAL RESOURCES

ICU, ITU, Respirators, Trained medical personnel.

PROBLEM

High rates of infection among medical staff hinder the actual capacity to treat critical patients.

# SITUATION EN CHILE

"We have today 1,567 people in the public health system infected and quarantined. In the private system the number is 672".

"Since March, the Society of Critical Care Medicine has trained over 30,000 people, nurses, physical therapists, and doctors of internal medicine or surgery in order to offer assistance to these units".

Subsecretary of Assistential Networks
La Tercera newspaper, 23 May 2020

# Intervention proposed by ISCI for care capacity.

## OUR IDEAS

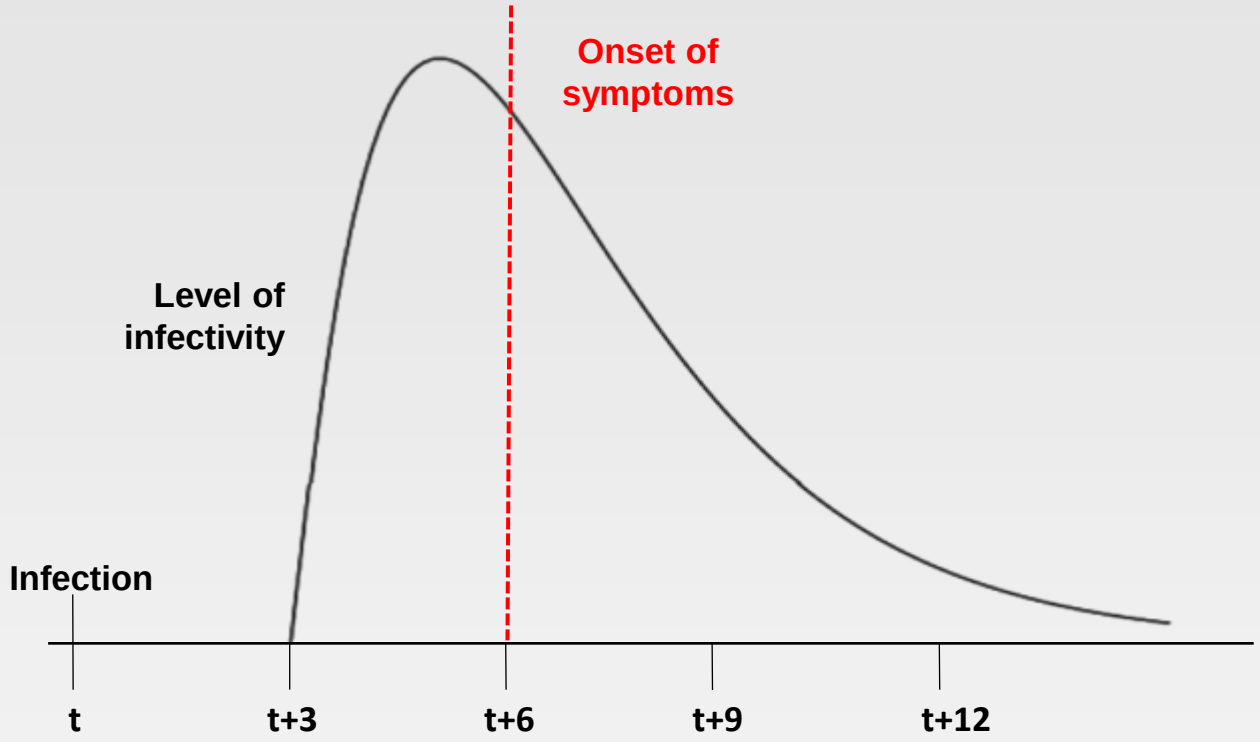
- The **design of work shifts that minimizes the probability of infection** among medical staff in order to maintain the care capacity throughout.
- **Dynamic optimization**, switching of shifts, hours, and location of staff as cases of infection appear.
- The system takes into account **specific situations of personnel** that could limit their ability to work certain shifts.
- A **visualization platform** that facilitates its implementation in practice.
- **Traceability to identify** members of staff with a **risk** of infection (tracking, tests, previous quarantine).
- **The integration of tech companies** with experience in some of the components of the integral solution.

We also propose

- **Strategic testing** of personnel via **PCR pool testing** to accelerate the return of equipment into the field and identify cases of infection quicker.
- **Tele-ICU**. Ventilators that display relevant information will place it online allowing experienced staff members to collaborate remotely with personnel in the field.

# SHIFT DESIGN

Recent studies have shown that **symptoms appear between 5 and 6 days after the date of infection**[1], while the period of infection begins **3 days prior to the onset of symptoms**[2].





1. Lauer, Stephen A., et al. "The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: estimation and application." Annals of internal medicine (2020).
2. He, Xi, et al. "Temporal dynamics in viral shedding and transmissibility of COVID-19." Nature medicine (2020): 1-4.

# SHIFT DESIGN

We require shift patterns that:

Reduce exposure to infection.

Benefit from the incubation period of the disease.

As a general rule, this can be achieved with shifts that combine:

- Concentrated work periods over 3-4 days.
- Long periods of rest (10 days approx.).
- Coordinated patterns that reduce the number of people who are exposed.

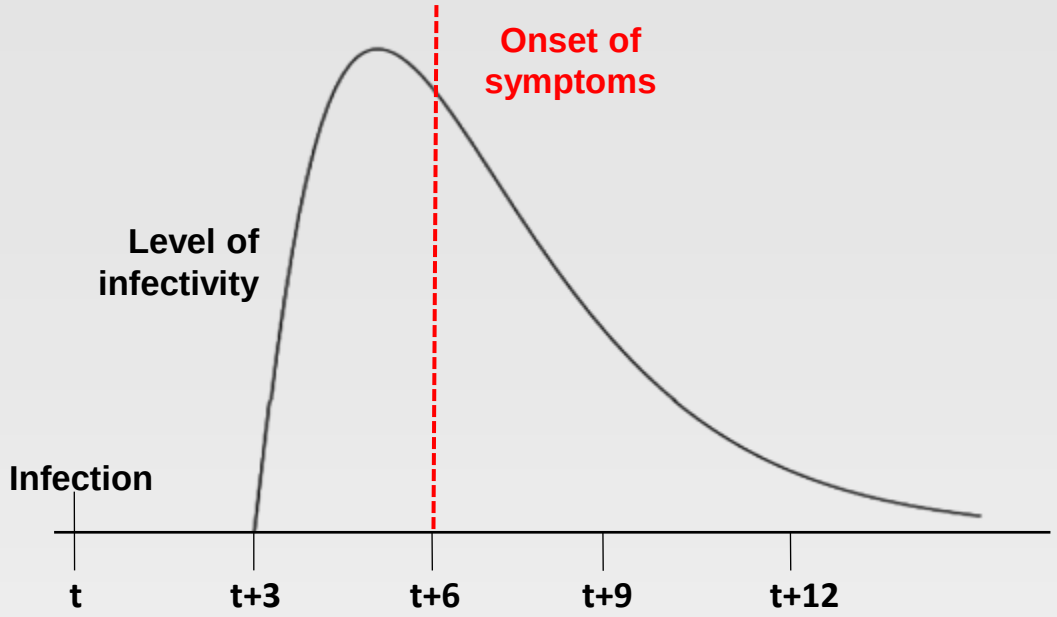
# REDUCING INFECTION

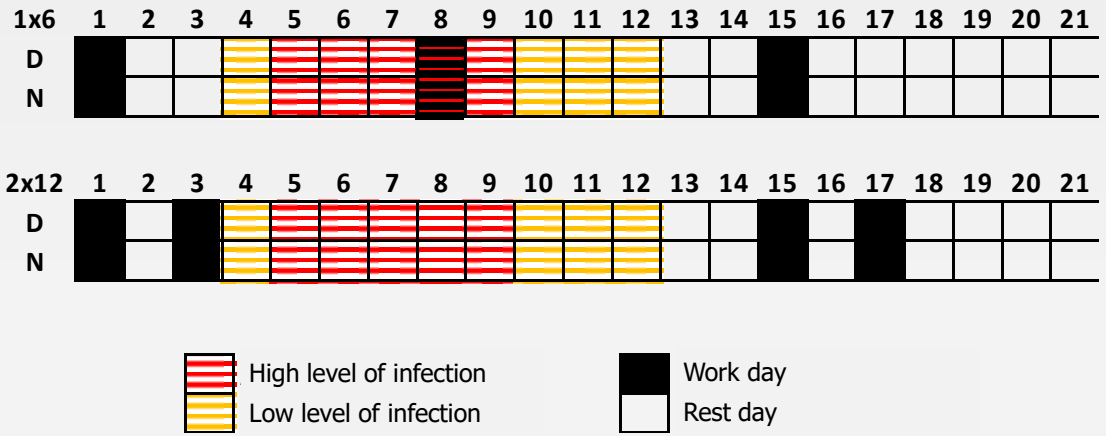
Supposing that on Day 1:

- Onset of symptoms approximately Day 6
- Infectious period commences approximately 3 days before the onset of symptoms[2]

A **1x6 shift** does not fully benefit from the incubation period and considers a return to hospital during the timeframe in which the risk of infection is high.

A **2x12 shift** makes the most of the evolution times of the illness by concentrating the workdays before the period of infection and considers a return once the risk of infection is low (the same would occur if infection took place on Day 3). This way, the risk of infection among medical staff is reduced.



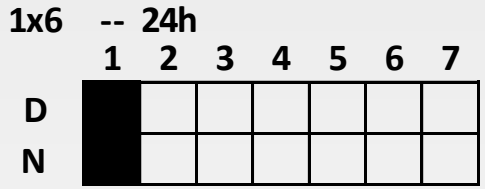



# RISK EVALUATION OF SHIFTS

Each shift has a base utilization determined by:

$$U_{base} = \frac{Hours\ Worked}{Total\ Hours}$$

On a 1x6 shift, in which 24 hours a week are worked, the base utilization is:




$$U_{base}^{1x6} = \frac{24\ hours}{168\ hours} = 14{,}3\%$$

# RISK EVALUATION OF SHIFTS

The number of shifts necessary $N_{base}$ for a permanent provision (24/7) of $D$ is determined by:

$$N_{base} = \frac{D}{U_{base}}$$

For a 1x6 shift of 24 hours per week, the number of shifts necessary to provide the ICU with three doctors 24/7 is:

$$N_{base}^{1x6} = \frac{3}{U_{base}^{1x6}} = \frac{3}{14{,}3\%} = 21$$

# SIMULATION MODEL

Interactions are modeled and use probabilities of infection (horizon of 24 week):

- With patients
- With members of medical staff
  - Function of the shift pattern and Personal Protection Equipment (EPP)
- Outside the hospital

# RISK EVALUATION OF SHIFTS

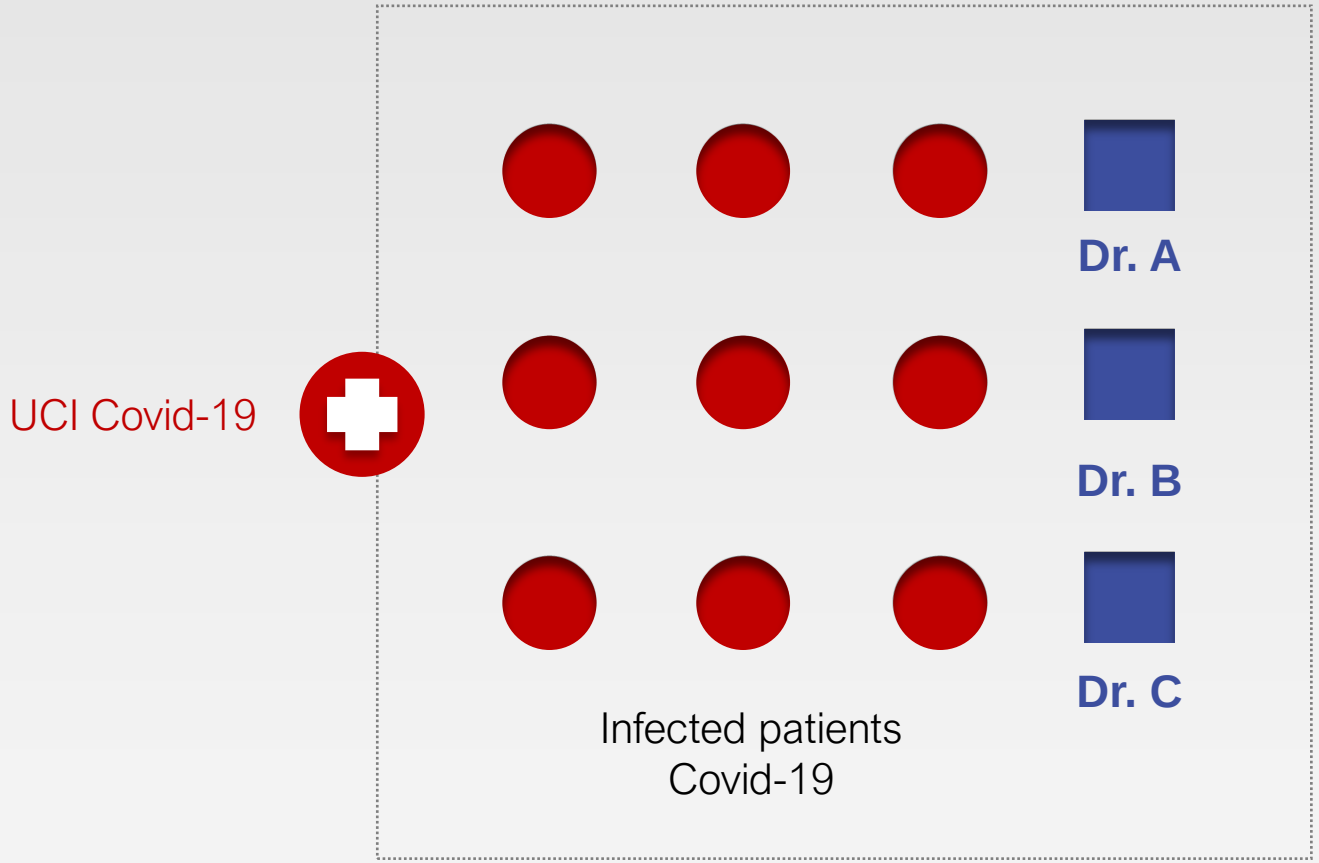
A risk of infection exists during every working day, which diminishes the availability of medical personnel due to preventive quarantine and periods of recovery in case of infection.

A simulation model was built that allows us to evaluate each shift in terms of the availability to work of medical staff, taking absenteeism into account.

The values of effective utilization $U_{ef}$ and effective quantity $N_{ef}$ for different shift configurations.

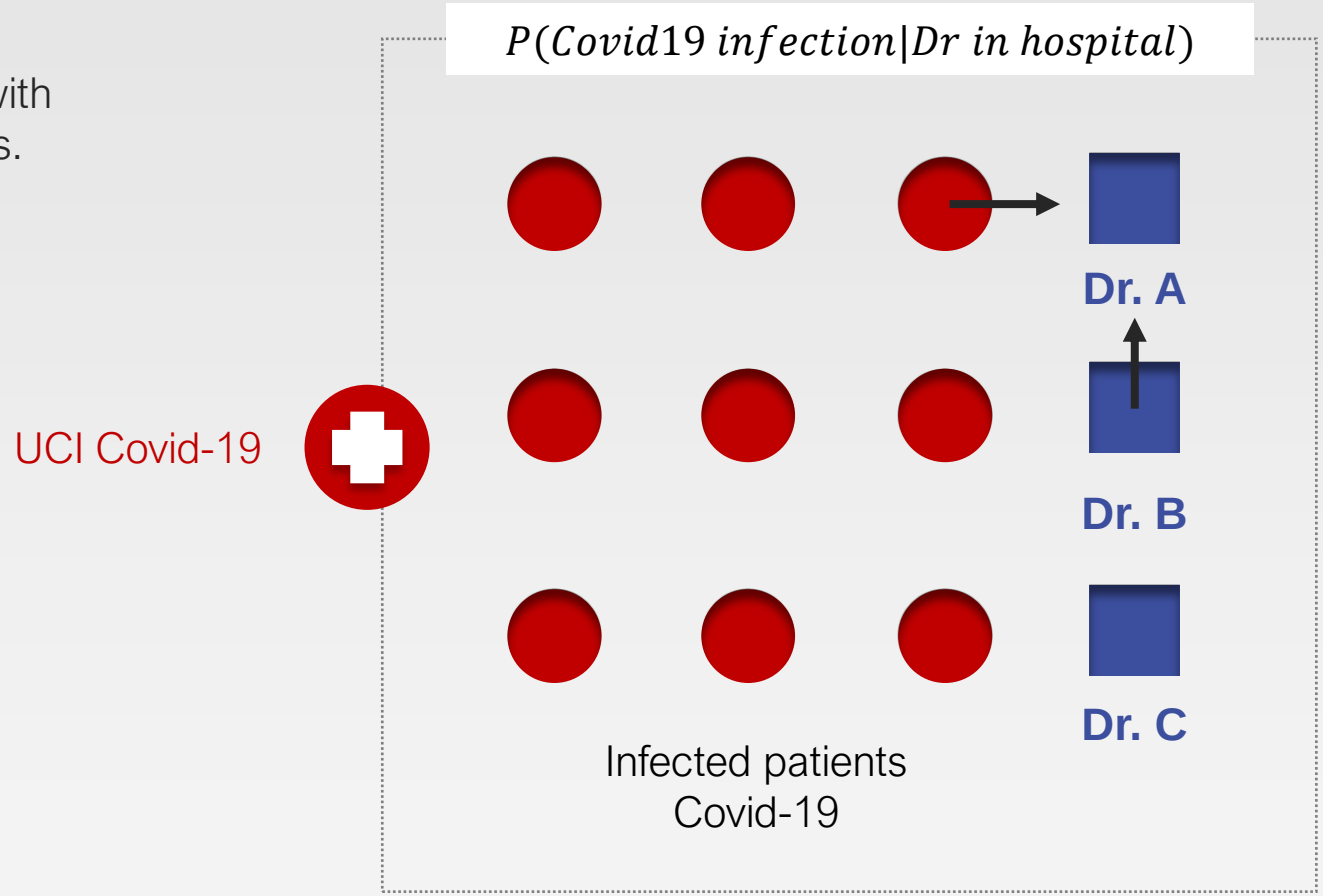
# SIMULATION OF DIFFERENT SHIFT PATTERNS

1/4 How does the simulation work?



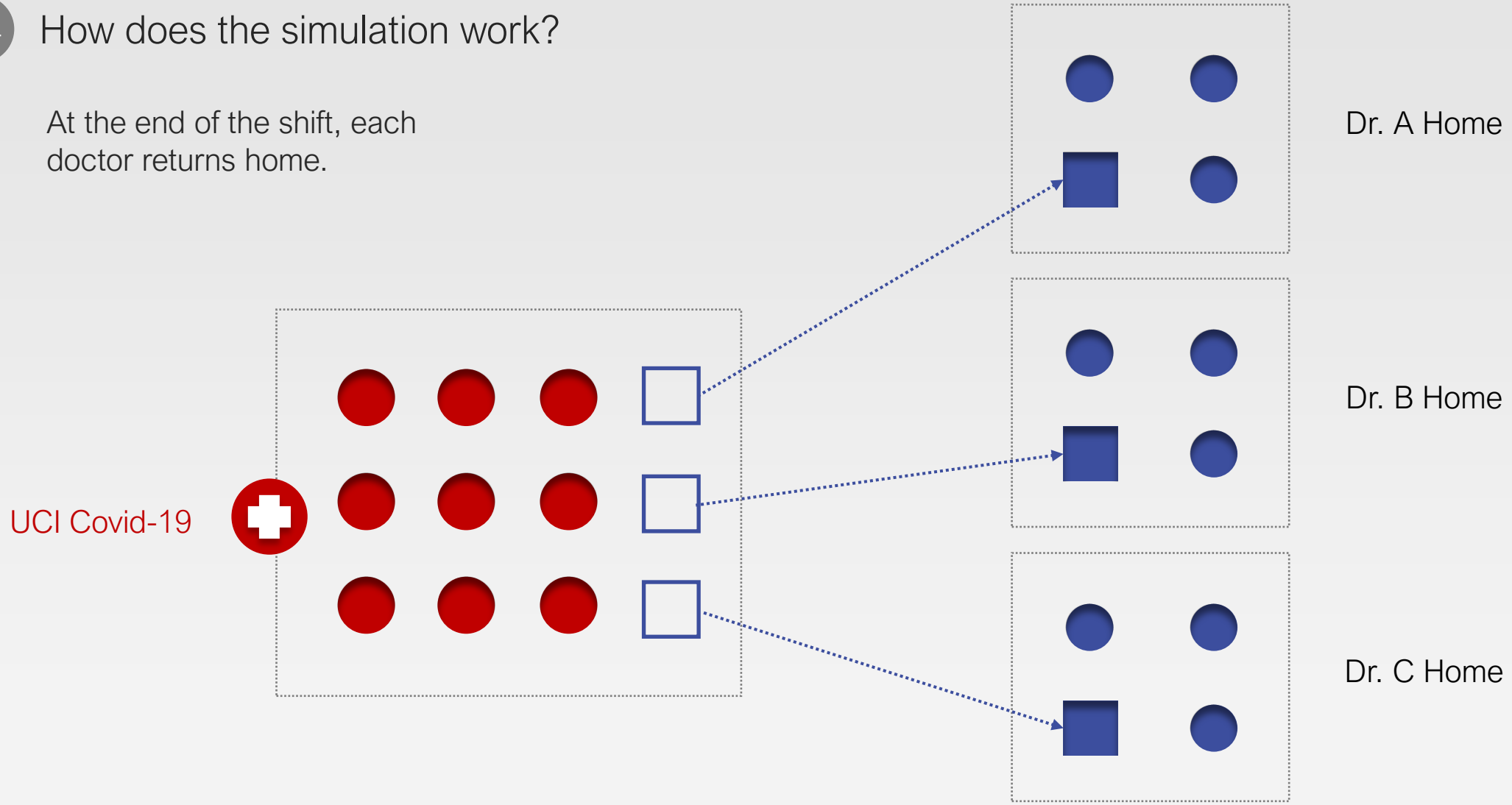
## 2/4 How does the simulation work?

On each shift doctors be infected through contact with their colleagues or patients.



## 3/4 How does the simulation work?

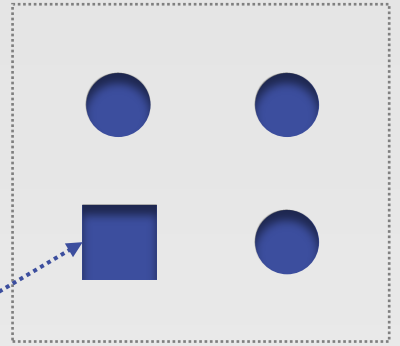
At the end of the shift, each doctor returns home.



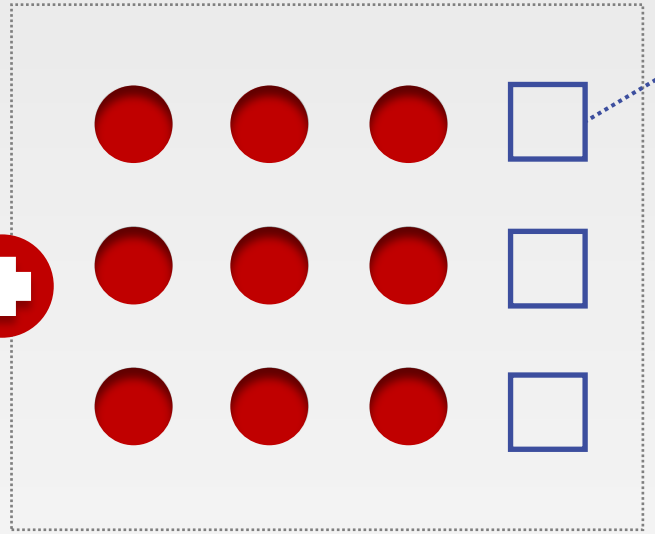
# SIMULATION OF DIFFERENT SHIFT PATTERNS

4/4 How does the simulation work?

Medical staff can be become infected outside the hospital.



Dr. A Home



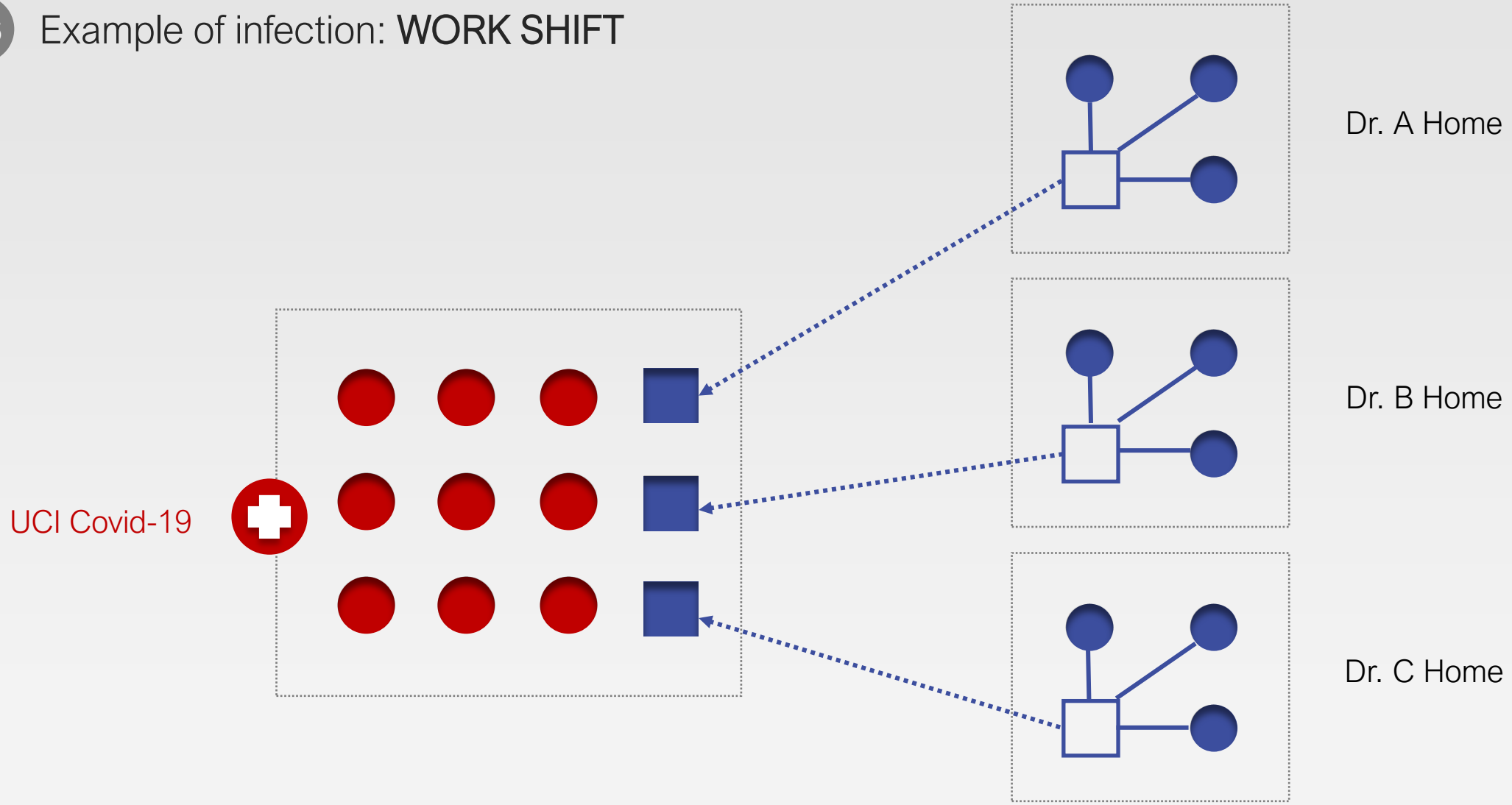
UCI Covid-19

$$P(Covid19\ infection|Dr\ outside\ the\ hospital)$$

# EXAMPLE 1

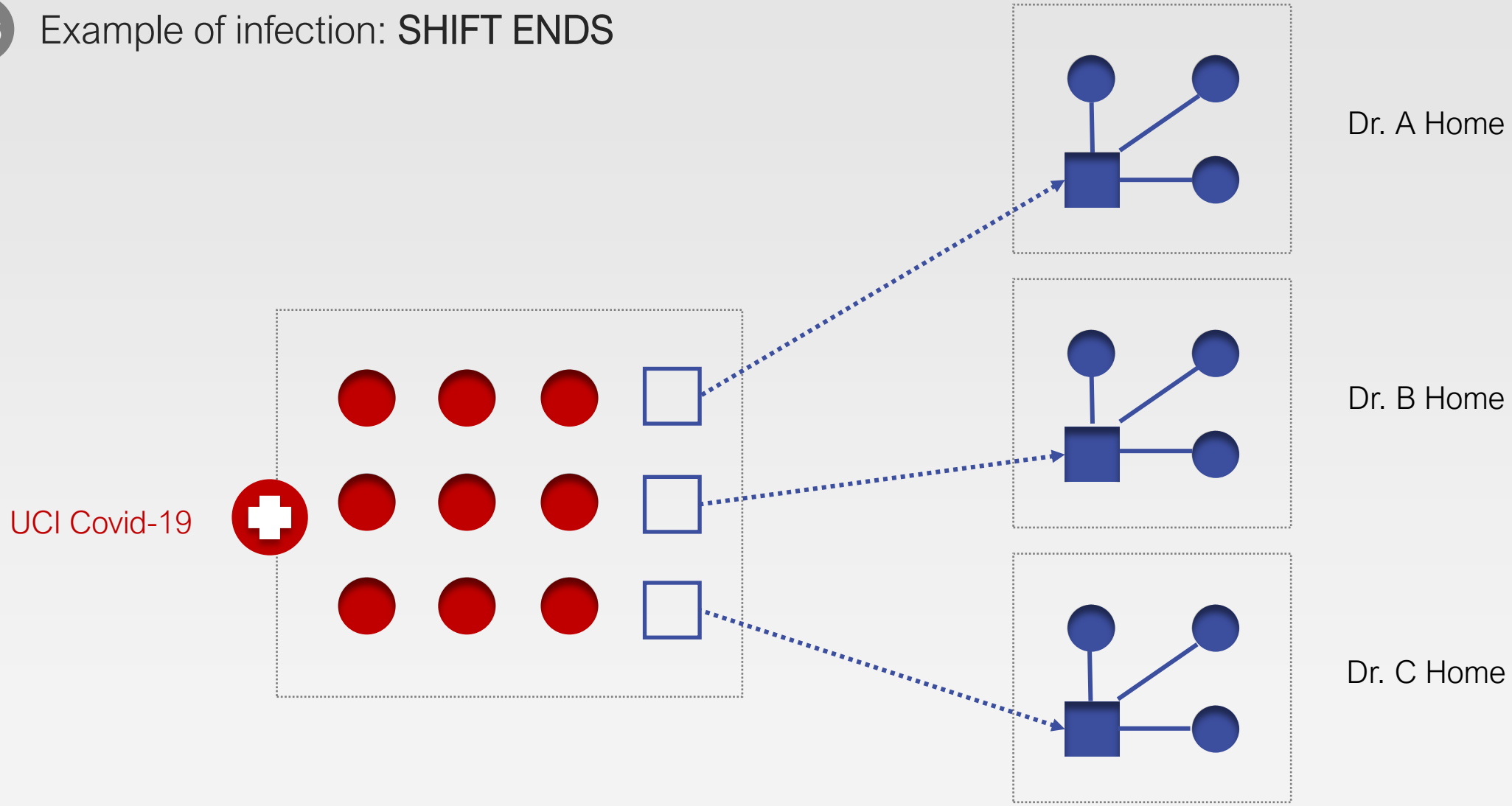
# SIMULATION OF DIFFERENT SHIFT PATTERNS

1/6 Example of infection: **WORK SHIFT**



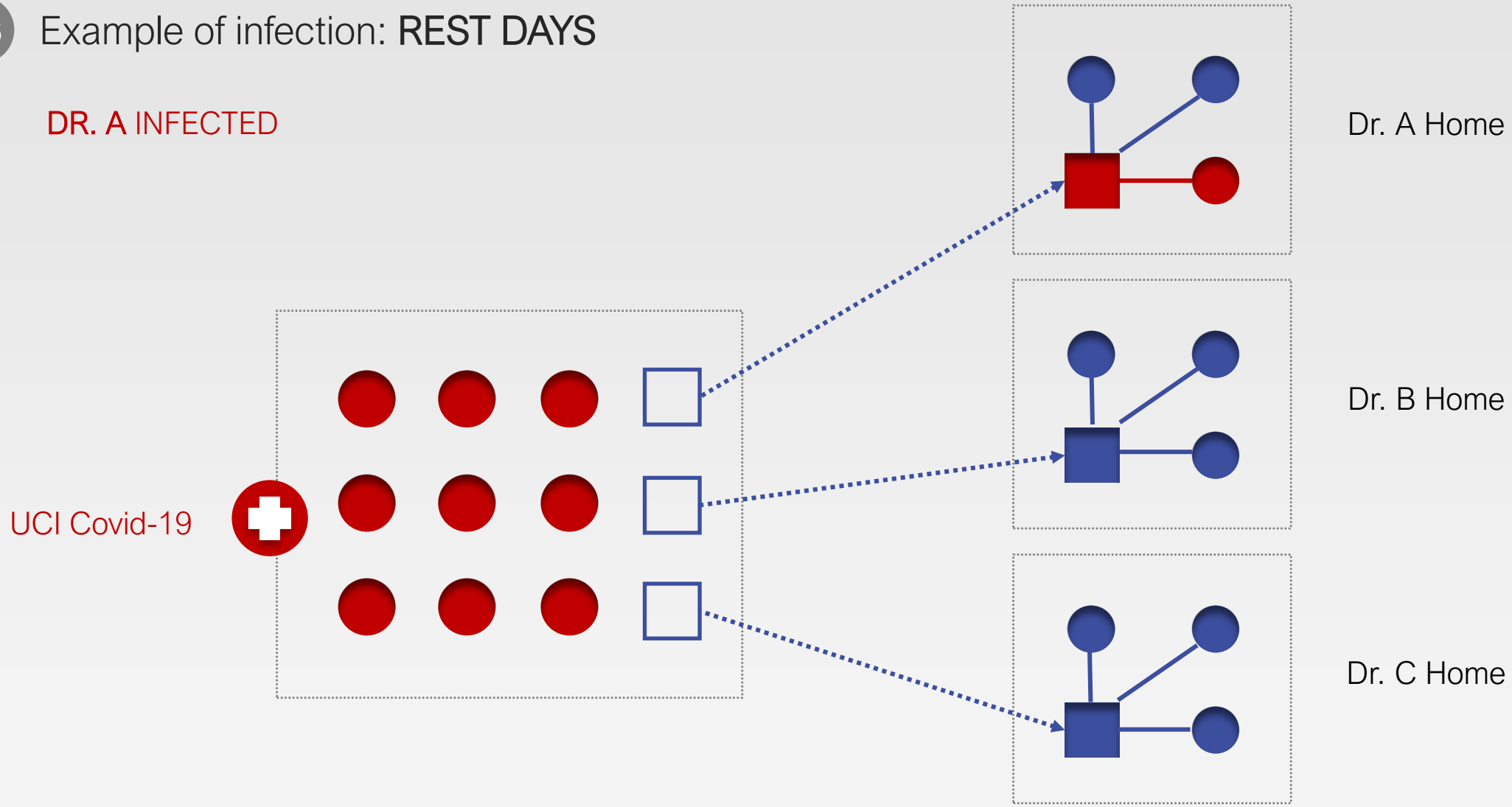
# SIMULATION OF DIFFERENT SHIFT PATTERNS

2/6 Example of infection: **SHIFT ENDS**



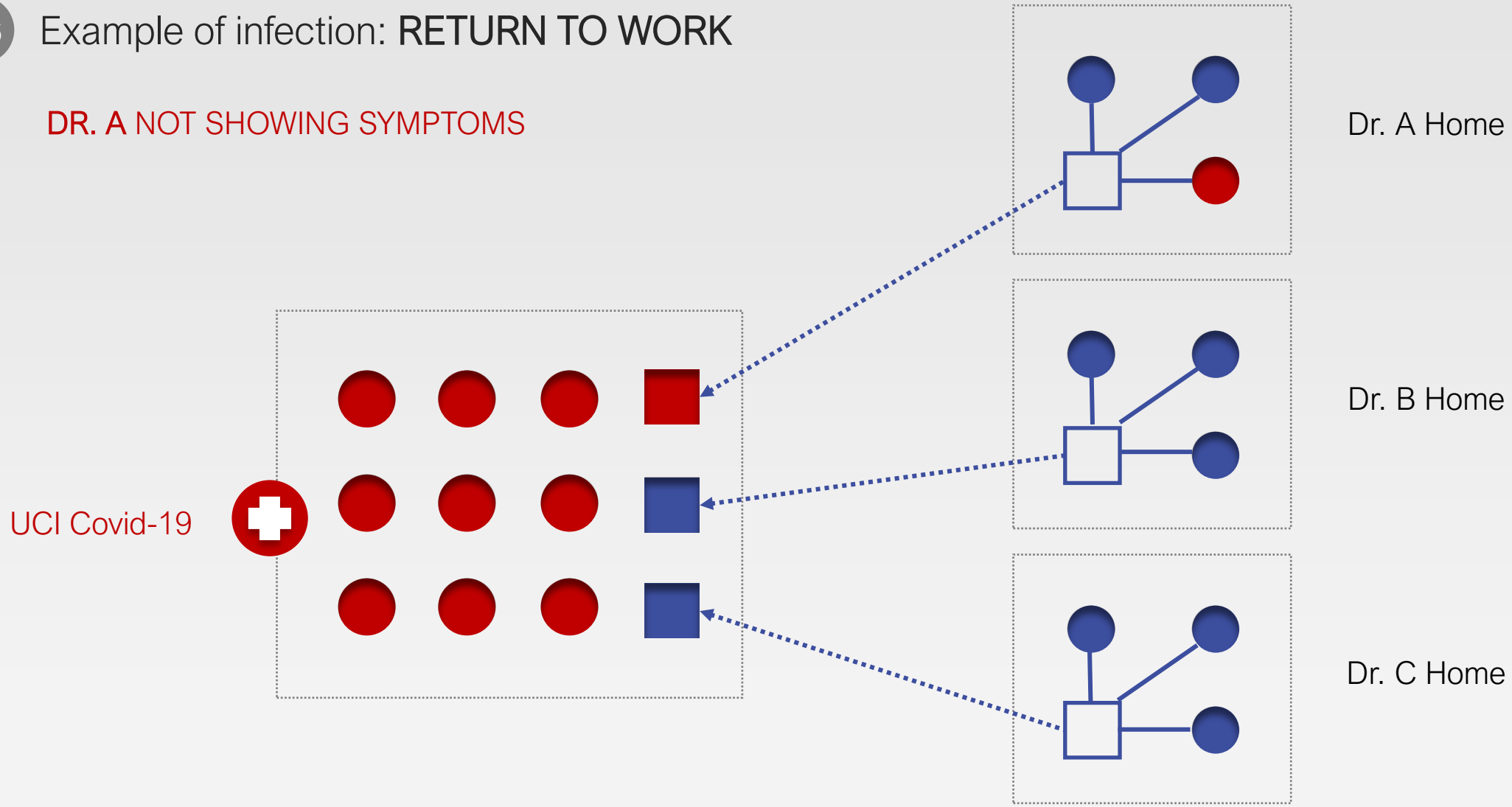
## 3/6 Example of infection: **REST DAYS**

DR. A INFECTED



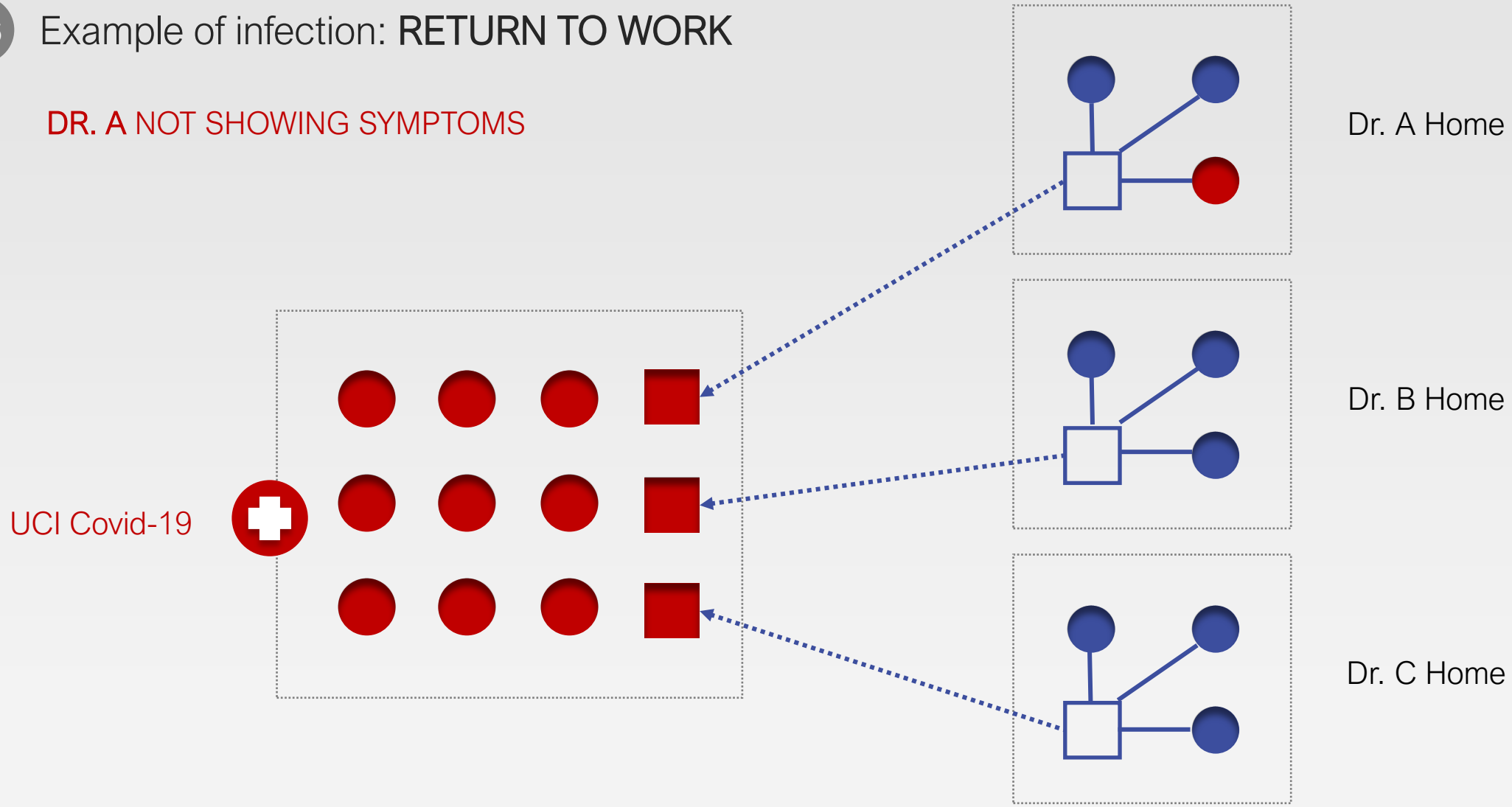
## 4/6 Example of infection: **RETURN TO WORK**

**DR. A** NOT SHOWING SYMPTOMS



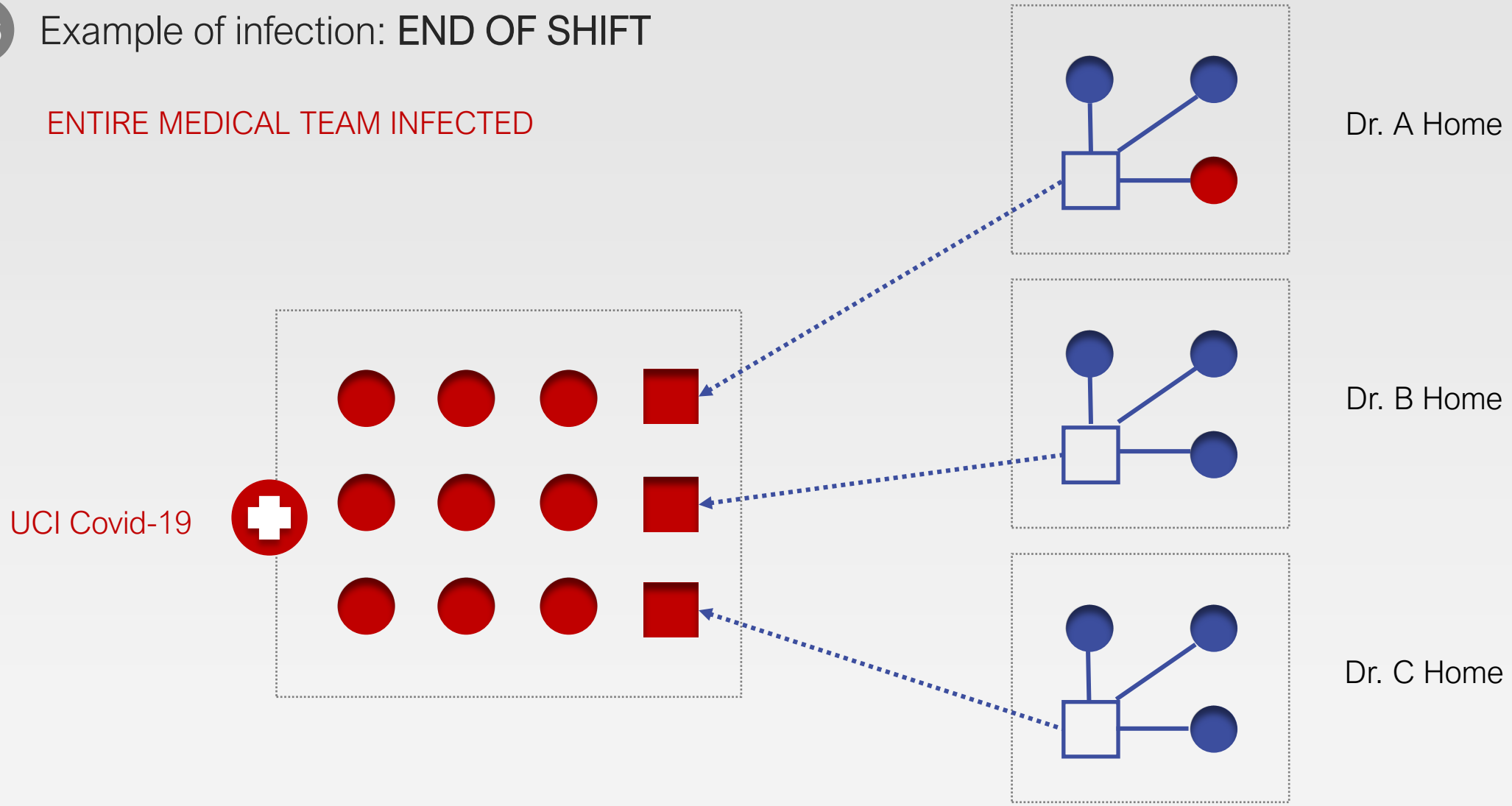
## 5/6 Example of infection: **RETURN TO WORK**

**DR. A** NOT SHOWING SYMPTOMS



## 6/6 Example of infection: **END OF SHIFT**

ENTIRE MEDICAL TEAM INFECTED



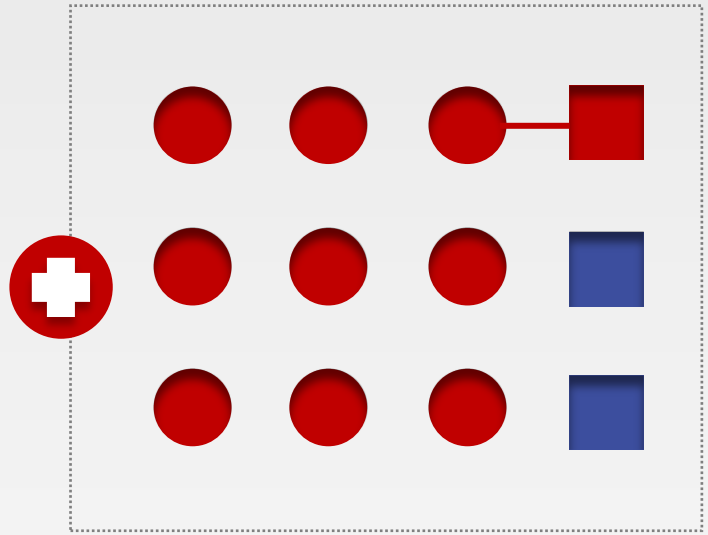
# EXAMPLE 2

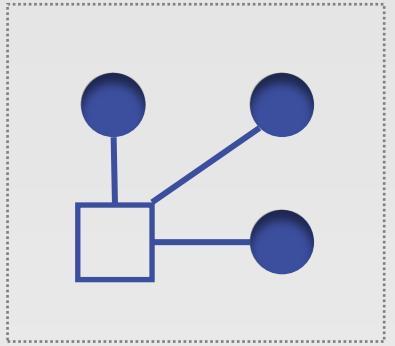
# SIMULATION OF DIFFERENT SHIFT PATTERNS

1/5 Example of infection: **WORK SHIFT**

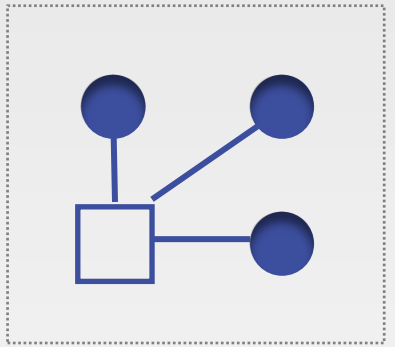
**DR. A** INFECTED BY A PATIENT

UCI Covid-19

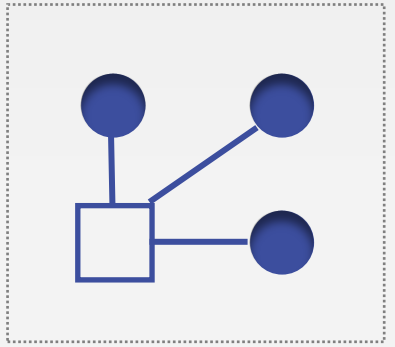




Dr. A Home



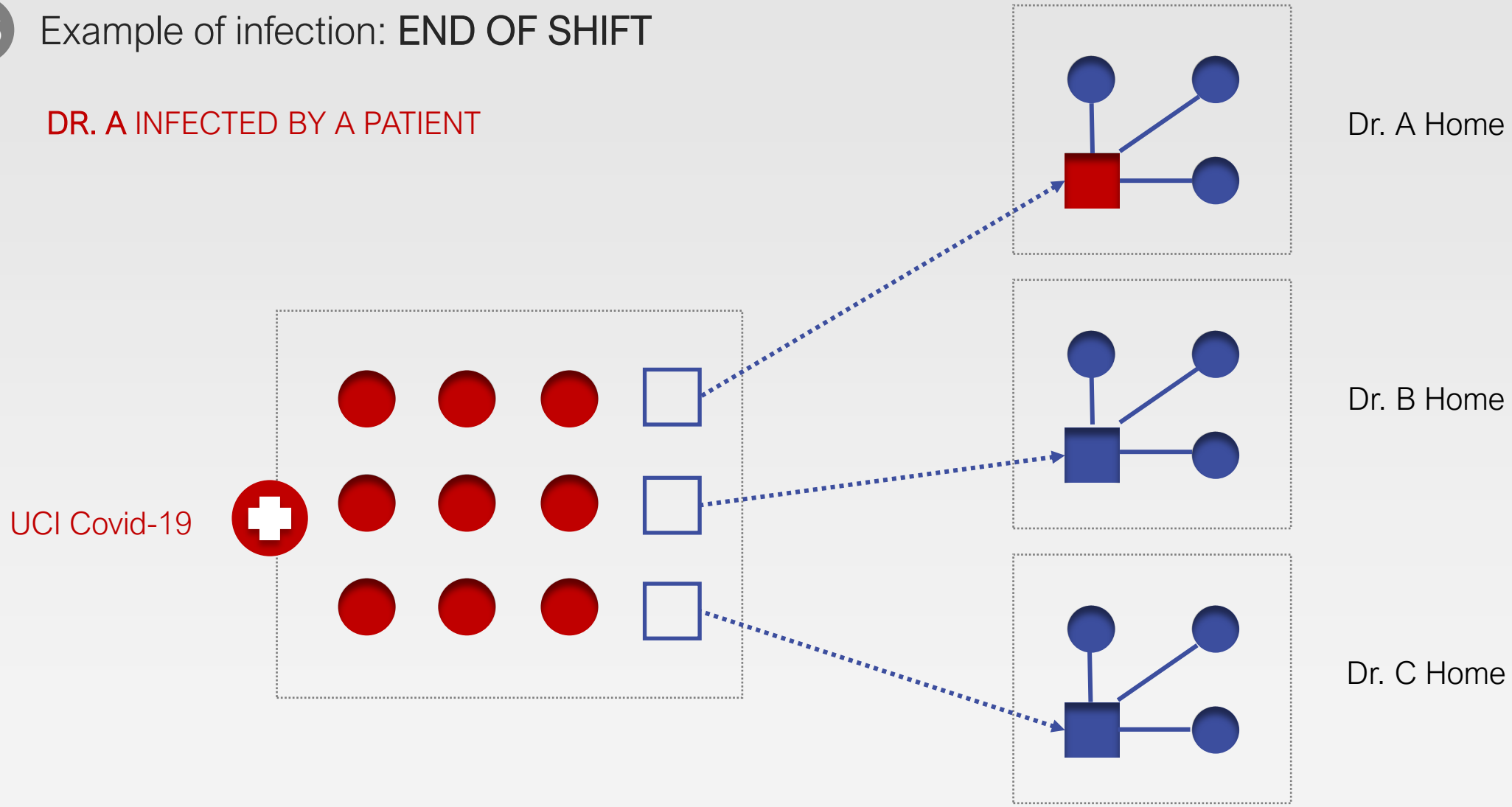
Dr. B Home



Dr. C Home

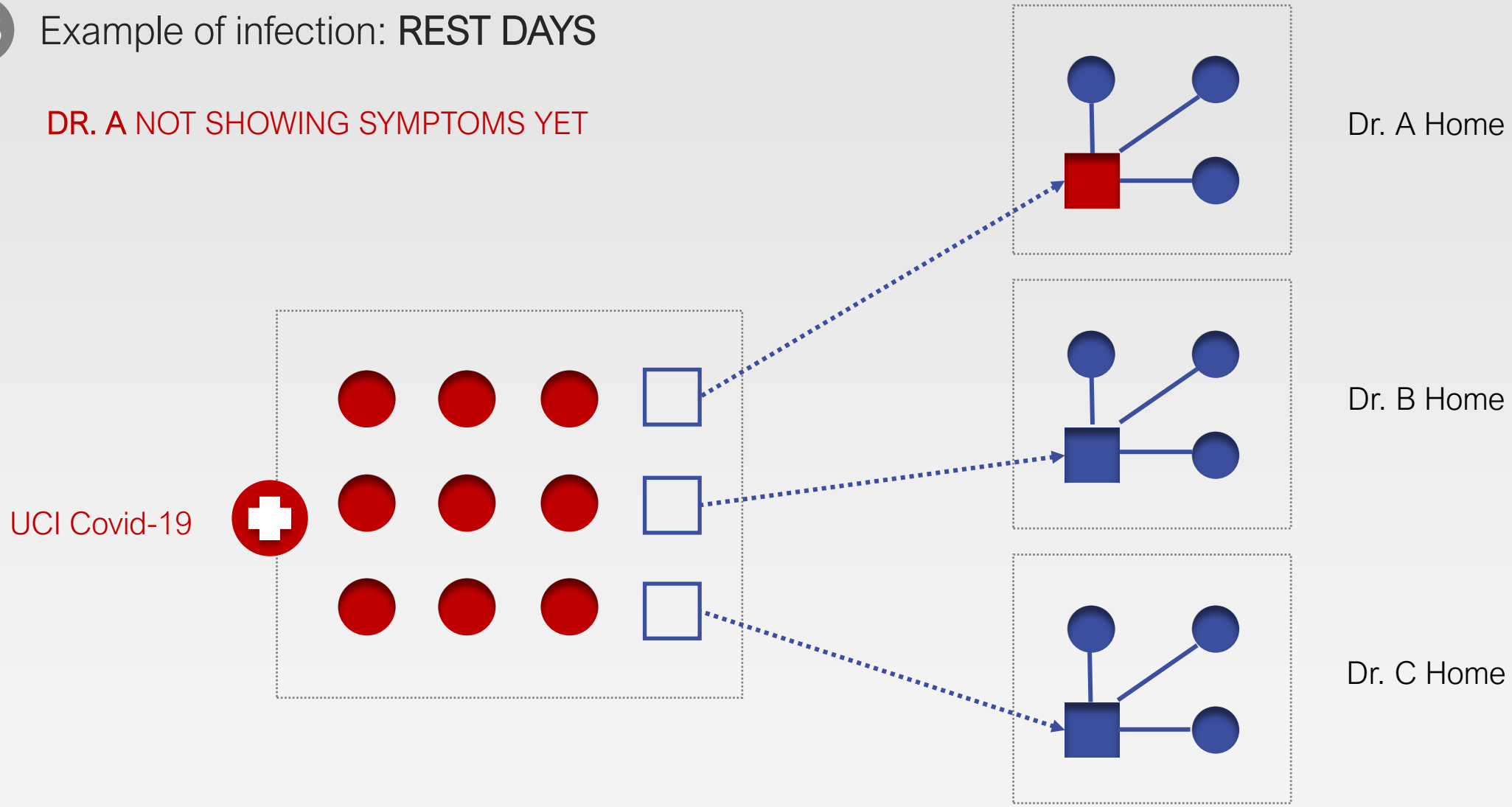
## 2/5 Example of infection: **END OF SHIFT**

**DR. A** INFECTED BY A PATIENT



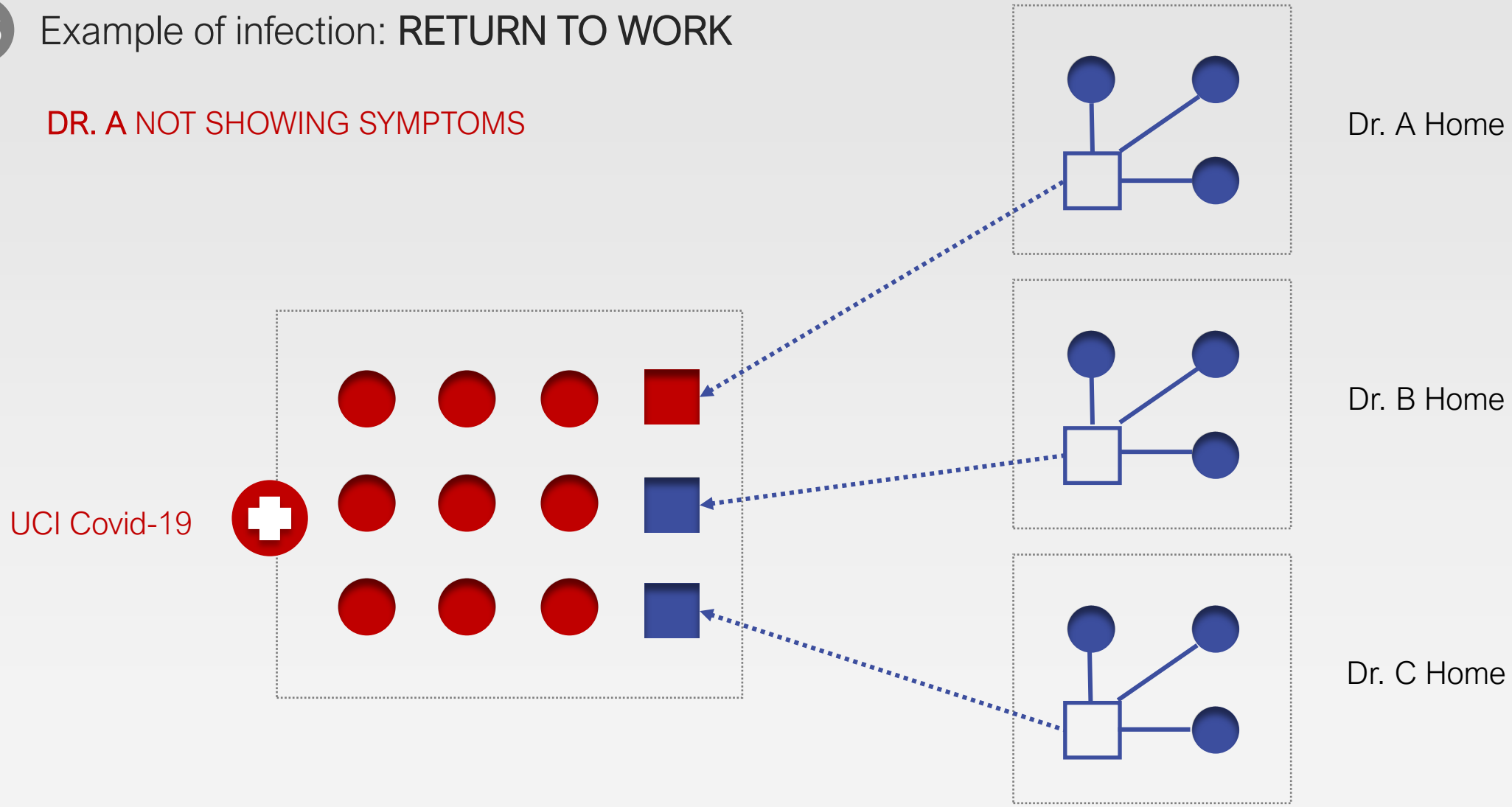
## 3/5 Example of infection: **REST DAYS**

**DR. A** NOT SHOWING SYMPTOMS YET



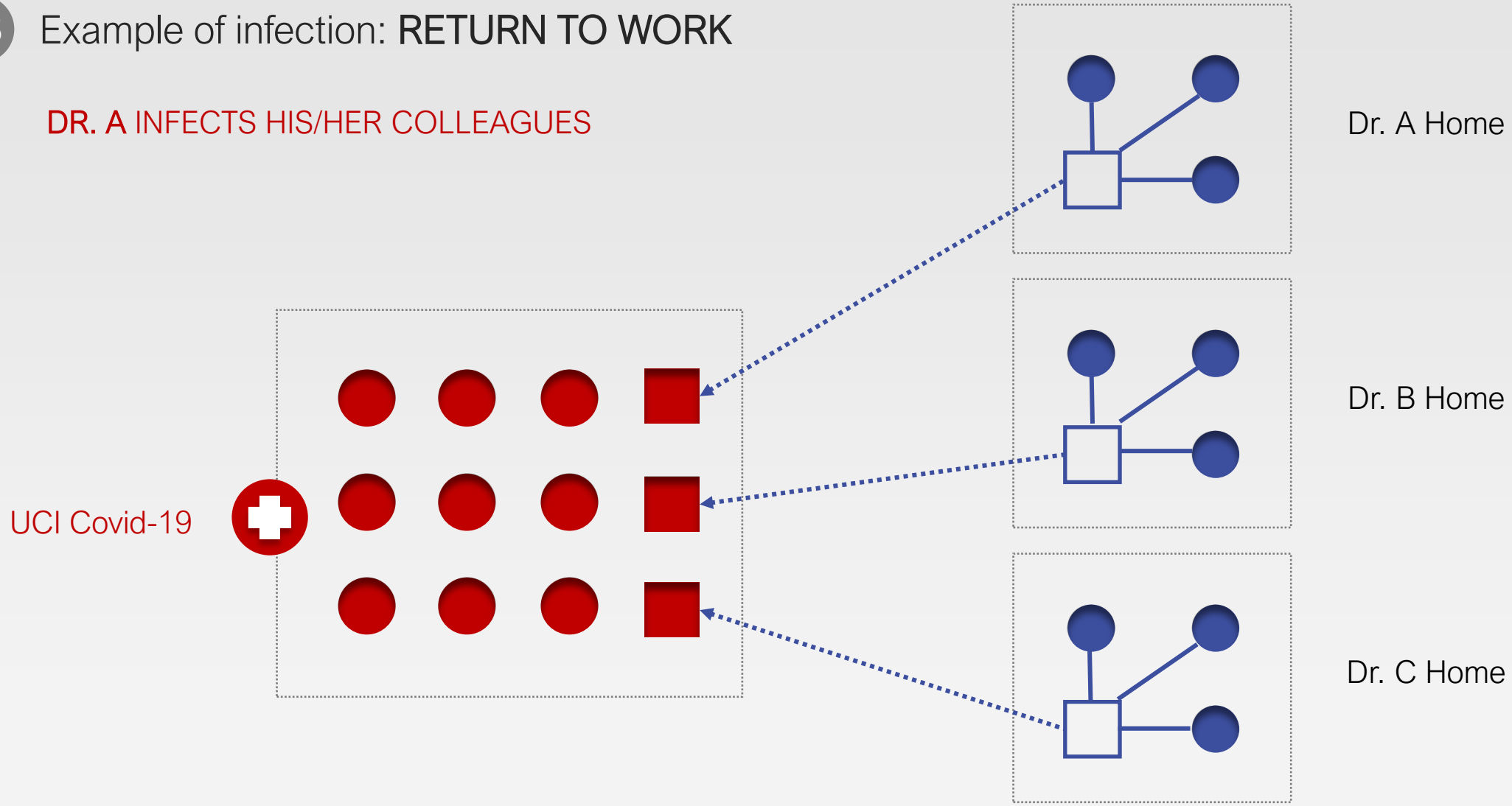
## 4/5 Example of infection: **RETURN TO WORK**

**DR. A** NOT SHOWING SYMPTOMS



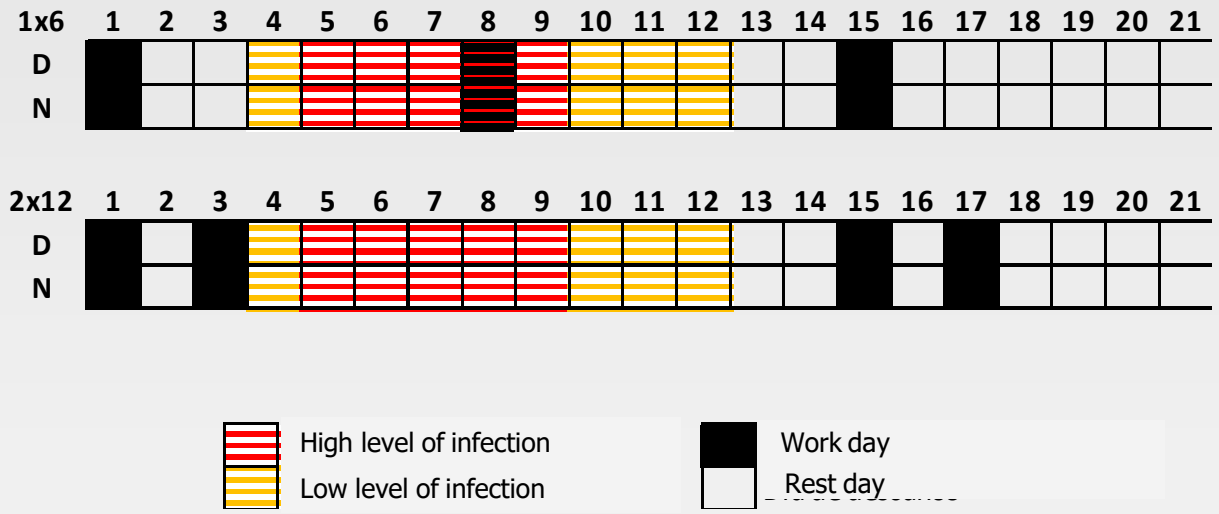
## 5/5 Example of infection: **RETURN TO WORK**

**DR. A** INFECTS HIS/HER COLLEAGUES



# REDUCING INFECTION

The results of the simulations show that the **probability of infection** between members of medical staff is as much as **4 times lower on a 2x12 shift** compared to a shift that considers on workday per week.



# REDUCING INFECTION

Proposal sent to the Hospital Clínico of the Universidad de Chile for their Critical Patient Unit campaign



Como se puede apreciar en la Tabla 2, que muestra la eficiencia y un indicador de riesgo de contagio relativo al turno 1x5 24h[1], estos esquemas de turno están entre los más riesgosos en términos de contagio. El turno 1x3 incluso tiene mayor riesgo de producir un contagio que esquemas de mayor utilización como el 4x10 con jornada de 24 horas (Figura 3).

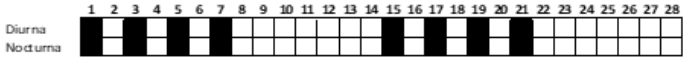



**Figura 3:** Esquema de turno 4x10 24h, que contempla cuatro jornadas de trabajo de 24 horas intercaladas con un día de descanso, seguidas por 7 días de descanso consecutivos.

| Turno | Días de trabajo | Días de descanso | Horas diarias | Horas semanales (promedio) | Eficiencia | Riesgo de contagio |
|---|---|---|---|---|---|---|
| 1x5 24h | 1 | 5 | 24 | 28 | 0.730 | 1.00 |
| 1x3 24h | 1 | 3 | 24 | 42 | 0.608 | 2.35 |
| 2x10 24h | 2 | 10 | 24 | 28 | 0.732 | 0.39 |
| 2x12 24h | 2 | 12 | 24 | 24 | 0.787 | 0.25 |
| 3x11 24h | 3 | 11 | 24 | 36 | 0.689 | 0.83 |
| 4x10 24h | 4 | 10 | 24 | 48 | 0.615 | 1.43 |
| 4x10 12h | 4 | 10 | 12 | 24 | 0.779 | 0.20 |

**Tabla 2:** Eficiencia y riesgo de contagio entre miembros del personal médico para algunos esquemas de turno, determinadas a través de una simulación que modela las interacciones del personal médico. El riesgo de contagio se reporta en relación al riesgo de contagio del turno 1x5 24h.

Se propone por tanto, para los tipos de jornada "Rotativo", utilizar turnos 2x10 24h (Figura 4), que permiten reducir en más de un 60% el riesgo de contagio entre miembros del equipo médico, manteniendo las mismas horas semanales promedio que el turno 1x5 24h, que corresponde al tipo de jornada "Rotativo". Este esquema permite mantener la dotación propuesta de 24 médicos generalistas y 48 médicos junior, disminuyendo considerablemente el riesgo de contagio.

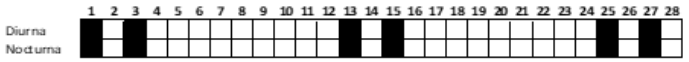



**Figura 4:** Esquema de turno 2x10 24h, que contempla dos jornadas de trabajo de 24 horas intercaladas con un día de descanso, seguidas por 9 días de descanso consecutivos.

[1] Este esquema de turno es utilizado frecuentemente en centros de atención médica de pacientes críticos.

# EFFICIENCY OF THE SHIFT PATTERNS

**24h**

| | | | High Protection | | Low Protection | |
|---|---|---|---|---|---|---|
| **Shift** | **Work Day** | **Hours per week** | **Low PPE** | **High PPE** | **Low PPE** | **High PPE** |
| 1 x 6 | 24h | 24h | 63,1% | 75,5% | 58,4% | 69,4% |
| 2 x 12 | 24h | 24h | 64,3% | 78,7% | 65,0% | 71,7% |
| 3 x 18 | 24h | 24h | 65,3% | 76,8% | 63,6% | 70,0% |
| 1 x 5 | 24h | 28h | 59,8% | 73,0% | 54,8% | 65,9% |
| 3 x 11 | 24h | 36h | 56,2% | 68,9% | 53,0% | 63,1% |
| 4 x 10 | 24h | 48h | 50,7% | 61,5% | 48,4% | 59,0% |
| 2 x 5 | 24h | 48h | 46,3% | 59,2% | 46,3% | 55,7% |

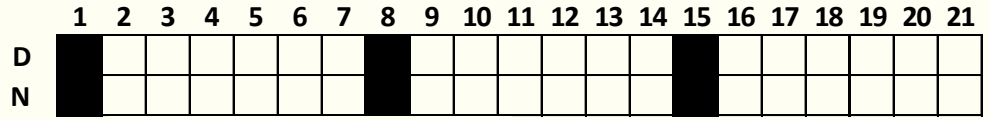
**Table 1**: Efficiency of selected shift schemes with a 24-hour working day. The efficiency is measured as the availability to meet the shift scheme while taking into account absenteeism as a result of quarantine or recovery periods.

# EFFICIENCY OF THE SHIFT PATTERNS

**24h**

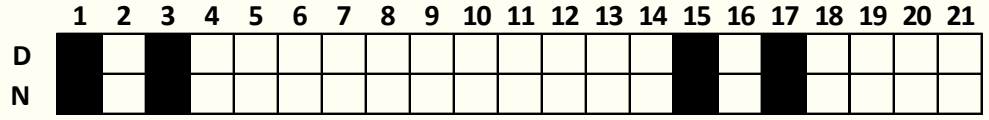
## SHIFT PATTERN

**1x6**



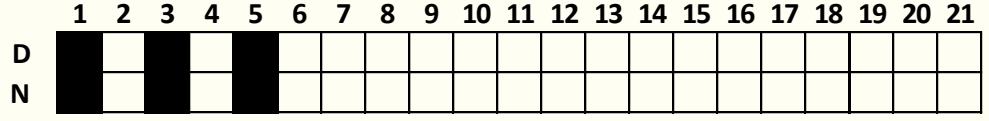

Average hours per week **24**

**2x12**



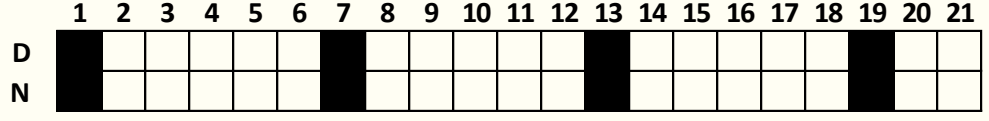

Average hours per week **24**

**3x18**



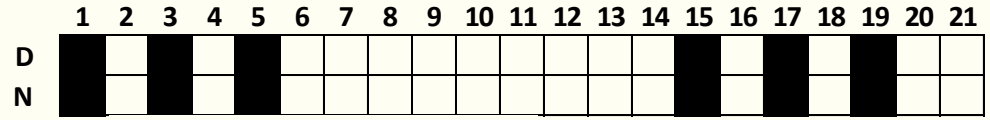

Average hours per week **24**

**1x5**



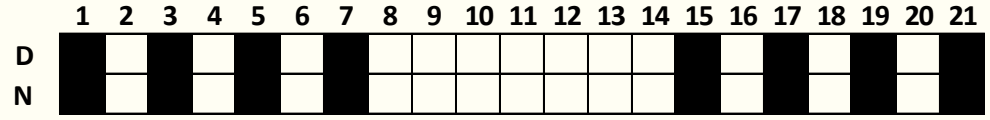

Average hours per week **28**

**3x11**



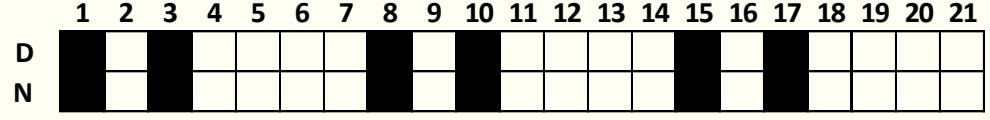

Average hours per week **36**

**4x10**




Average hours per week **48**

**2x5**




Average hours per week **48**

Work day
Rest day

# EFFICIENCY OF THE SHIFT PATTERNS

12h

| Shift | Work Day | Hours per week | High Protection outside hospital | | Low Protection outside hospital | |
|---|---|---|---|---|---|---|
| | | | Low PPE | High PPE | Low PPE | High PPE |
| 3 x 11 | 12h | 18h | 70,7% | 82,7% | 66,4% | 78,0% |
| 4 x 10 | 12h | 24h | 65,2% | 77,9% | 62,2% | 72,9% |
| 2 x 5 | 12h | 24h | 60,2% | 75,8% | 56,0% | 69,7% |
| 2 x 5* | 12h | 24h | 60,4% | 72,3% | 56,3% | 69,1% |
| 5 x 9 | 12h | 30h | 61,2% | 72,5% | 57,5% | 67,9% |
| 3 x 4 | 12h | 36h | 51,6% | 63,8% | 49,1% | 62,0% |
| 4 x 3 | 12h | 48h | 44,9% | 57,7% | 44,6% | 55,4% |

* Shift with one rest day between workdays.

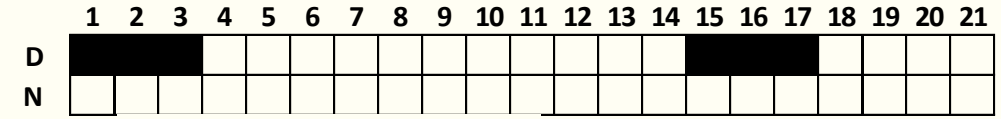
**Table 2:** Efficiency of selected shift schemes with a 12-hour working day. The efficiency is measured as the availability to meet the shift scheme while taking into account absenteeism as a result of quarantine or recovery periods.

# EFFICIENCY OF THE SHIFT PATTERNS

**12h**

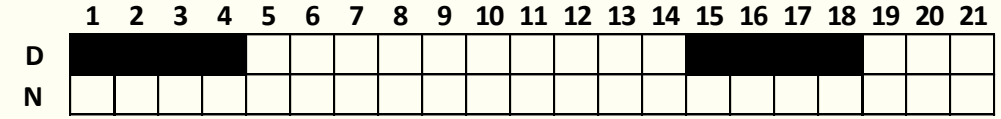
## SHIFT PATTERN

**3x11**



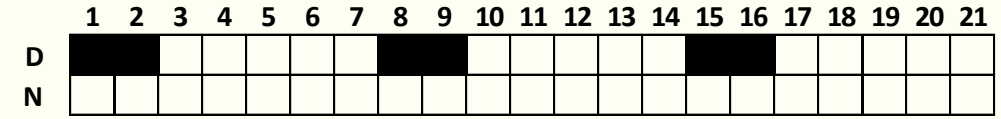

Average hours per week **18**

**4x10**



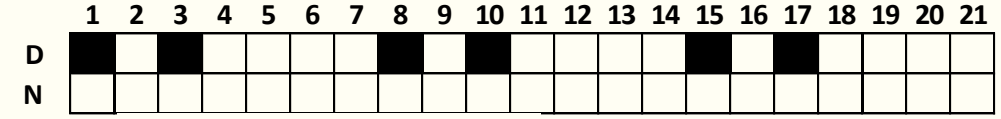

Average hours per week **24**

**2x5**



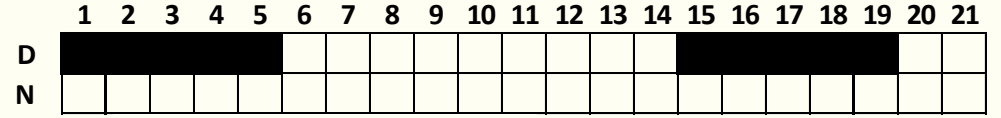

Average hours per week **24**

**2x5***



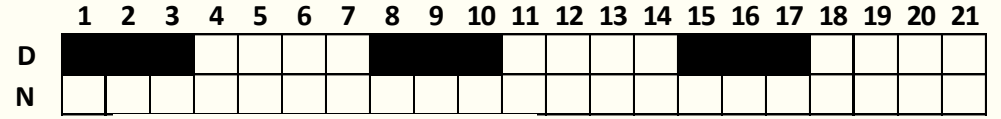

Average hours per week **24**

**5x9**



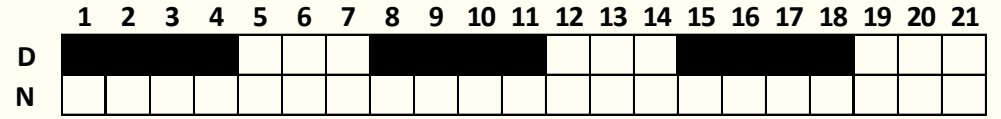

Average hours per week **30**

**3x4**




Average hours per week **36**

**4x3**




Average hours per week **48**

Work day

Rest day

# DEFINITION OF FEASIBLE SHIFTS (ÑUBLE)

- Each member of the ICU medical staff is asked in detail the shift configurations they are able to work.

- The survey considers multiple configurations of shift with workdays of 12 hours and 24 hours, and of between 18 and 48 hours per week.

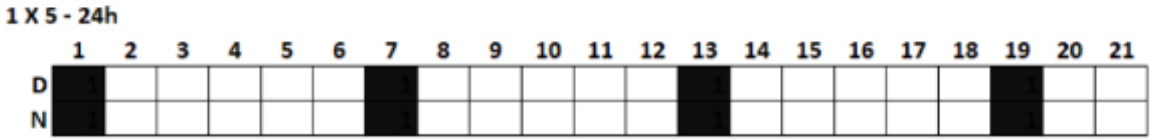
SURVEY

The following shows different work schemes. Analyze each one thoroughly.

In terms of the following options, **would you be available to work the shift patterns described below?**

*Please remember that the first day of work could be any day of the week, after which you will be asked about your specific availability.*

Pattern 1:




Average weekly hours: 28.0

Yes | No

# ASSIGNMENT OF SHIFTS

An integer programing model was developed that makes it possible to identify shift assignments that minimize the risk of infection in the hospital.

.

Contracts of each member of the critical care team become restrictions along with their availability expressed in the survey.

# DEFINITION OF FEASIBLE SHIFTS

- Each member of the ICU medical staff is asked in detail the shift configurations they are able to work.

- The survey considers multiple configurations of shift with workdays of 12 hours and 24 hours, and of between 18 and 48 hours per week.

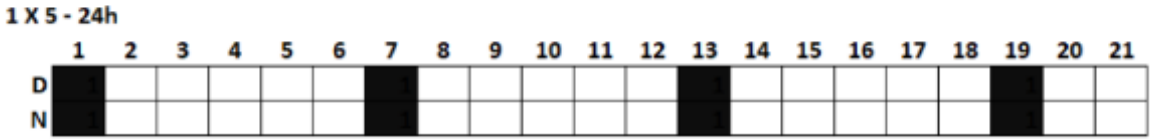
SURVEY

The following shows different work schemes. Analyze each one thoroughly.

In terms of the following options, **would you be available to work the shift patterns described below?**

*Please remember that the first day of work could be any day of the week, after which you will be asked about your specific availability.*

Pattern 1:

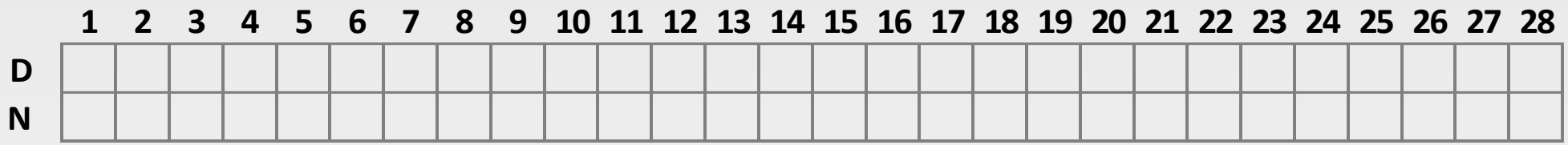



Average weekly hours: 28.0

Yes | No

# DEFINITION OF FEASIBLE SHIFTS

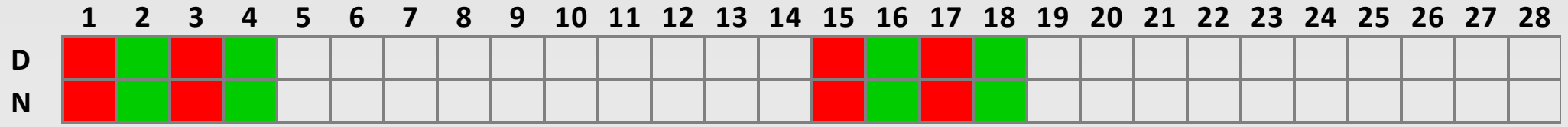
## Example of planning



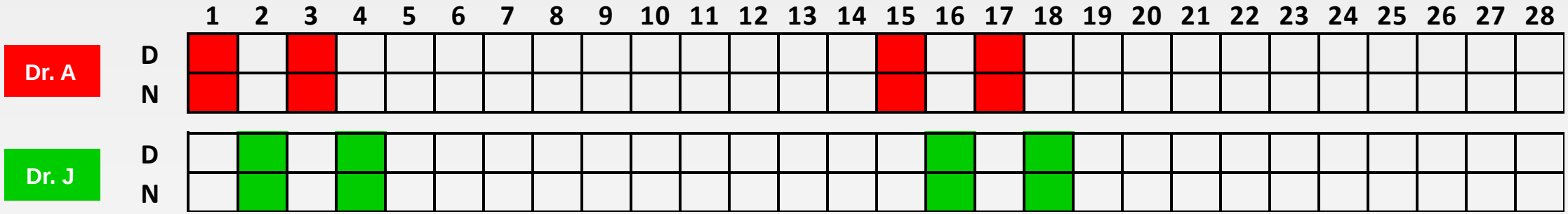

It is necessary to assign shifts to doctors in such a way that it covers the entire planning horizon.

# DEFINITION OF FEASIBLE SHIFTS

## Example of planning

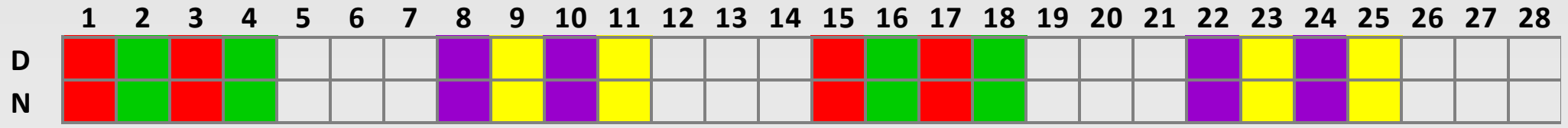



- 2 shifts of 2x12 – 24h

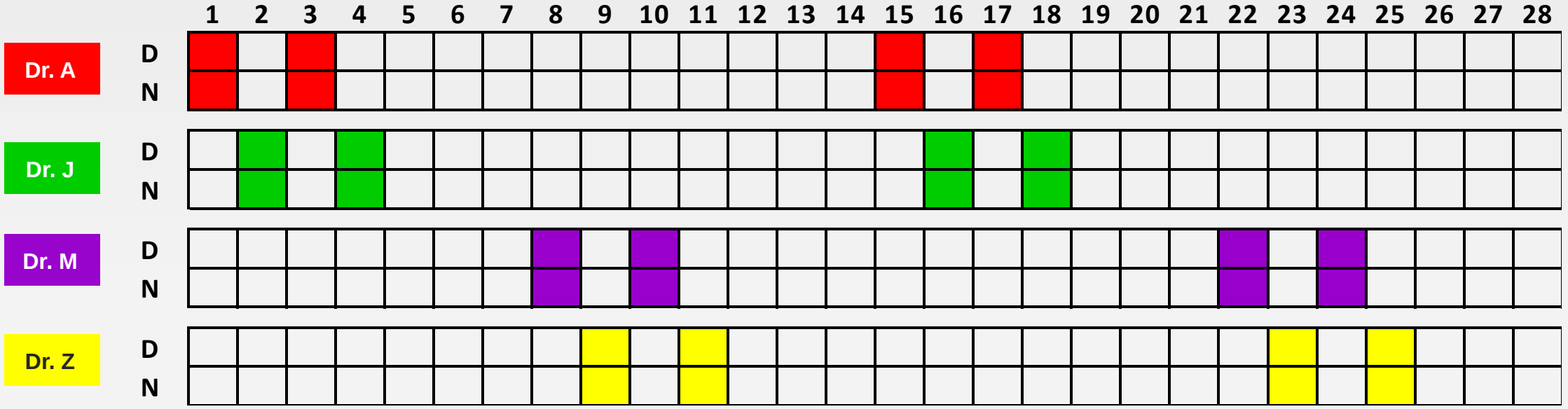


# DEFINITION OF FEASIBLE SHIFTS

## Example of planning

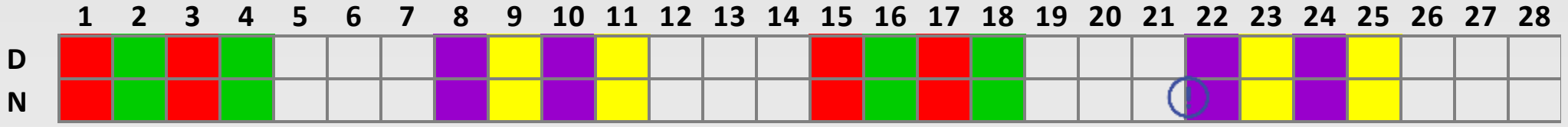



- 4 shifts of 2x12 – 24h



# DEFINITION OF FEASIBLE SHIFTS

## Example of planning




4 shifts of 2x12 with a 24h working day is assigned, covering days:

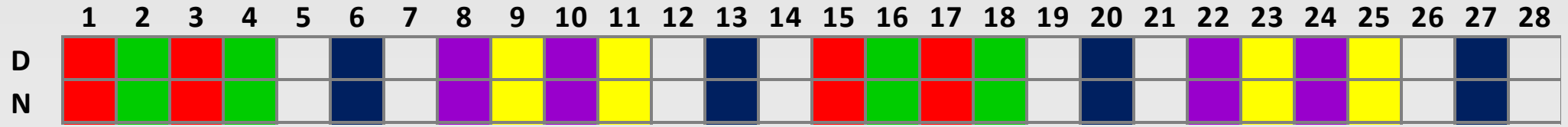
- **Dr. A** 1, 3, 15 and 17
- **Dr. J** 2, 4, 16 and 18
- **Dr. M** 8, 10, 22 and 24
- **Dr. Z** 9, 11, 23 and 25

It is necessary to assign more shifts to cover days:

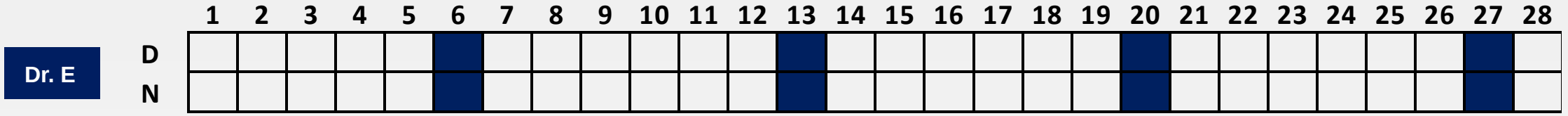
5-7, 12-14, 19-21 and 26-28

# DEFINITION OF FEASIBLE SHIFTS

## Example of planning

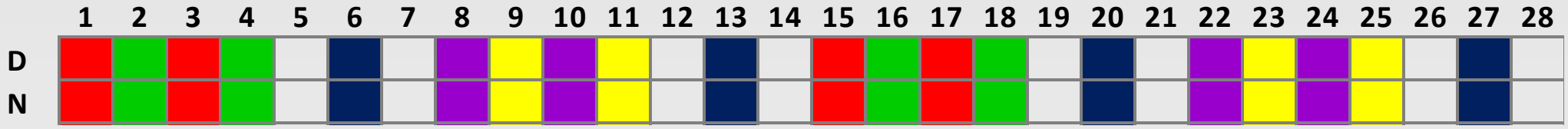



- 1 shift of 1x6 – 24h



# DEFINITION OF FEASIBLE SHIFTS

## Example of planning




4 shifts of 2x12 with a 24-hour working day are assigned, covering days:

| | |
|---|---|
| **Dr. A** | 1, 3, 15 and 17 |
| **Dr. J** | 2, 4, 16 and 18 |
| **Dr. M** | 8, 10, 22 and 24 |
| **Dr. Z** | 9, 11, 23 and 25 |

A 1x6 shift with a working day of 24 hours is assigned, covering the days:

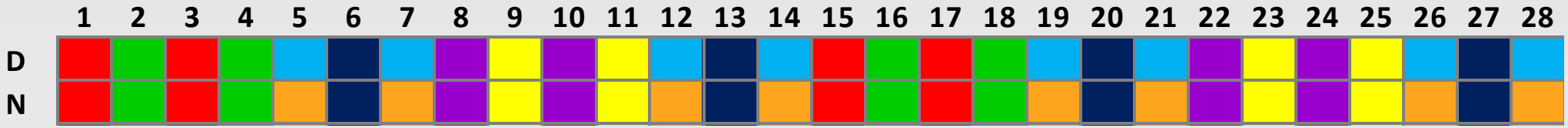
| | |
|---|---|
| **Dr. E** | 6, 13, 20 and 27 |

It is necessary to assign more shifts to cover days:

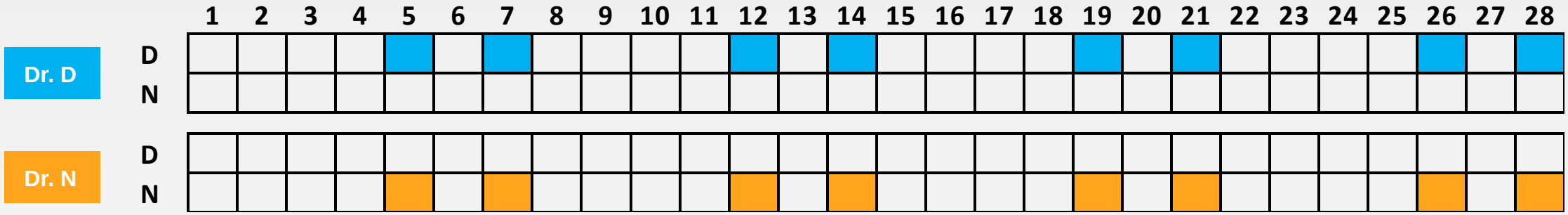
5, 7, 12, 14, 19, 21, 26 and 28

# DEFINITION OF FEASIBLE SHIFTS

## Example of planning

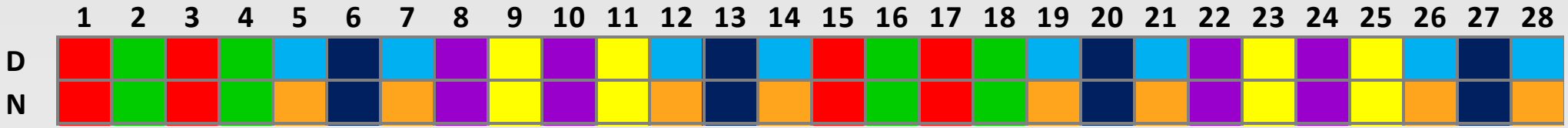



- 2 shifts of 2x5 –12h



# DEFINITION OF FEASIBLE SHIFTS

## Example of planning




4 shifts of 2x12 with a 24-hour working day are assigned, covering days:

- **Dr. A** — 1, 3, 15 and 17
- **Dr. J** — 2, 4, 16 and 18
- **Dr. M** — 8, 10, 22 and 24
- **Dr. Z** — 9, 11, 23 and 25

A 1x6 shift with a working day of is assigned, covering the days:

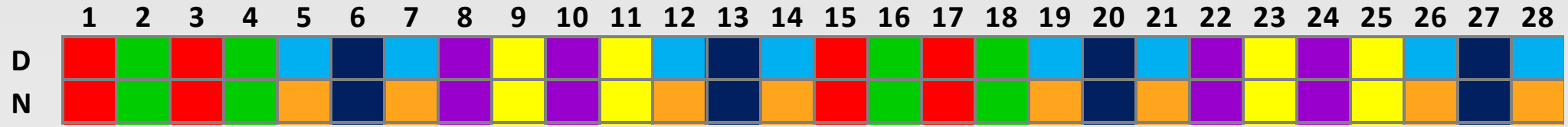
- **Dr. E** — 6, 13, 20 and 27

2 2x5 shifts with a 24-hour working day are assigned, covering the days:

- **Dr. D** — 5, 7, 12, 14, 19, 21, 26 y 28 during the day
- **Dr. N** — 5, 7, 12, 14, 19, 21, 26 y 28 during the night

# DEFINITION OF FEASIBLE SHIFTS

## Example of planning




This scheme uses seven shifts to provide the ICU with a doctor 24/7:

4 shifts of 2x12 (24-hour workdays)

1 shifts of 1x6 (24-hour workdays)

2 shifts of 2x5 (12-hour workdays)

Each one of these 7 shifts equals a 24-hour working week.

A permanent capacity of $N$ doctors can be achieved by repeating this scheme $N$ times.

# SHIFT PROBLEMS

Intelligenxia
Data Driven Solutions

The project has the backing of the company **Intelligenxia**, which has created a platform that allows us to:

- Keep each doctor informed regarding the shifts they must work over a 2-month planning horizon.
- Visualize on a temporary horizon of one month the calendar which doctors have been assigned to which shift.
- Carry out changes in planned shifts.
- Integrate attendance control systems.

# SHIFT PLATFORM
# Intelligenxia

Intelligenxia
Data Driven Solutions

## Semana 14

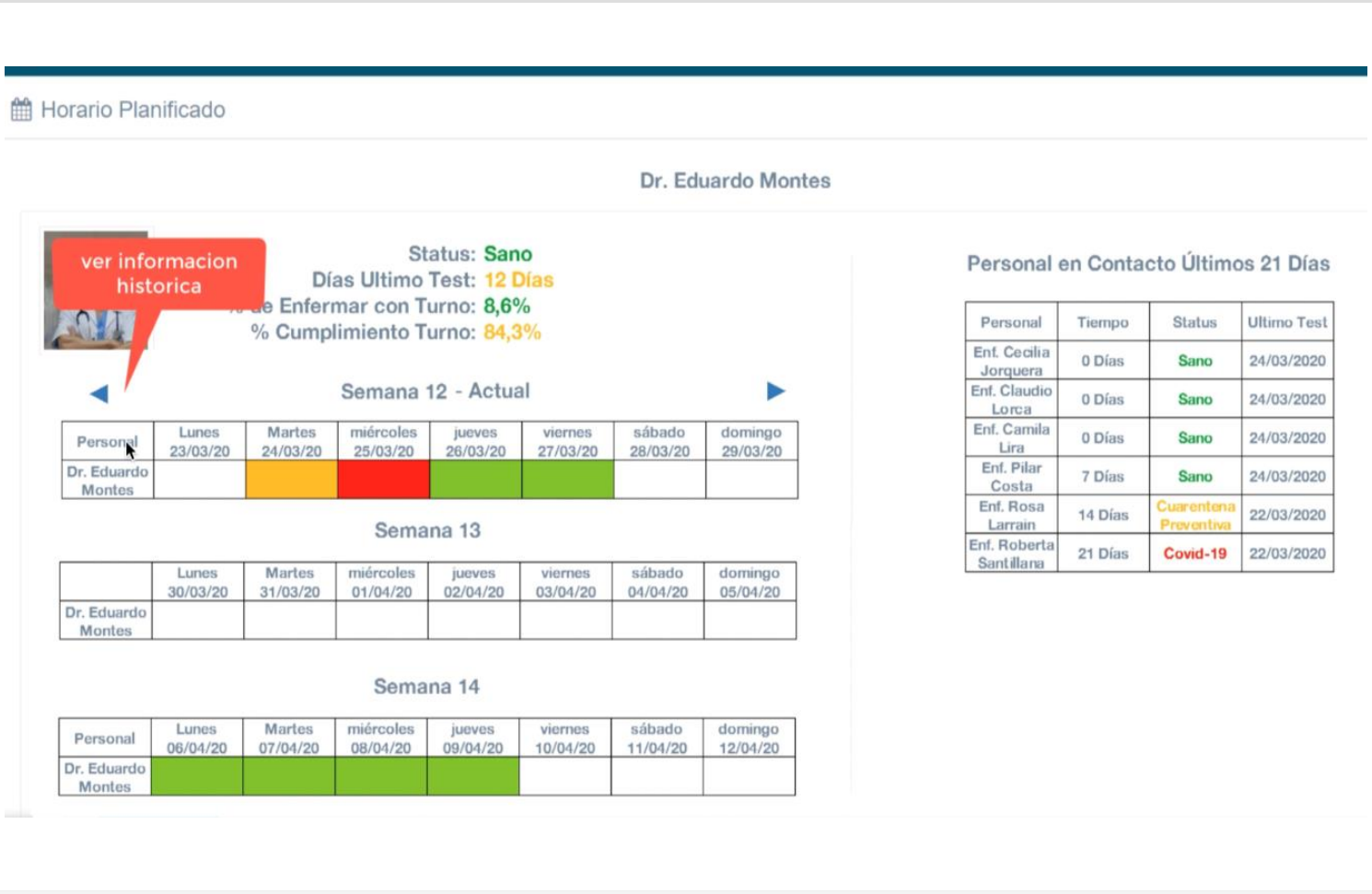
| Personal | Lunes 06/04/20 | Martes 07/04/20 | miércoles 08/04/20 | jueves 09/04/20 | viernes 10/04/20 | sábado 11/04/20 | domingo 12/04/20 |
|---|---|---|---|---|---|---|---|
| Dr. Eduardo Montes | | | | | | | |
| Enf. Cecilia Jorquera | | | | | | | |
| Enf. Claudio Lorca | | | | | | | |
| Enf. Camila Lira | | | | | | | |
| Dr. Pedro Reyes | | | | | | | |
| Enf. Pilar Costa | | | | | | | |
| Enf. Sofia Briones | | | | | | | |
| Enf. Roberto Santis | | | | | | | |

## Semana 15

| | Lunes 13/04/20 | Martes 14/04/20 | miércoles 15/04/20 | jueves 16/04/20 | viernes 17/04/20 | sábado 18/04/20 | domingo 19/04/20 |
|---|---|---|---|---|---|---|---|
| Dr. Eduardo Montes | | | | | | | |
| Enf. Cecilia Jorquera | | | | | | | |
| Enf. Claudio Lorca | | | | | | | |
| Enf. Camila Lira | | | | | | | |
| Dr. Pedro Reyes | | | | | | | |
| Enf. Pilar Costa | | | | | | | |
| Enf. Sofia Briones | | | | | | | |
| Enf. Roberto Santis | | | | | | | |

# SHIFT PLATFORM
# Intelligenxia

Intelligenxia
Data Driven Solutions



# TRACEABILITY

Unholster

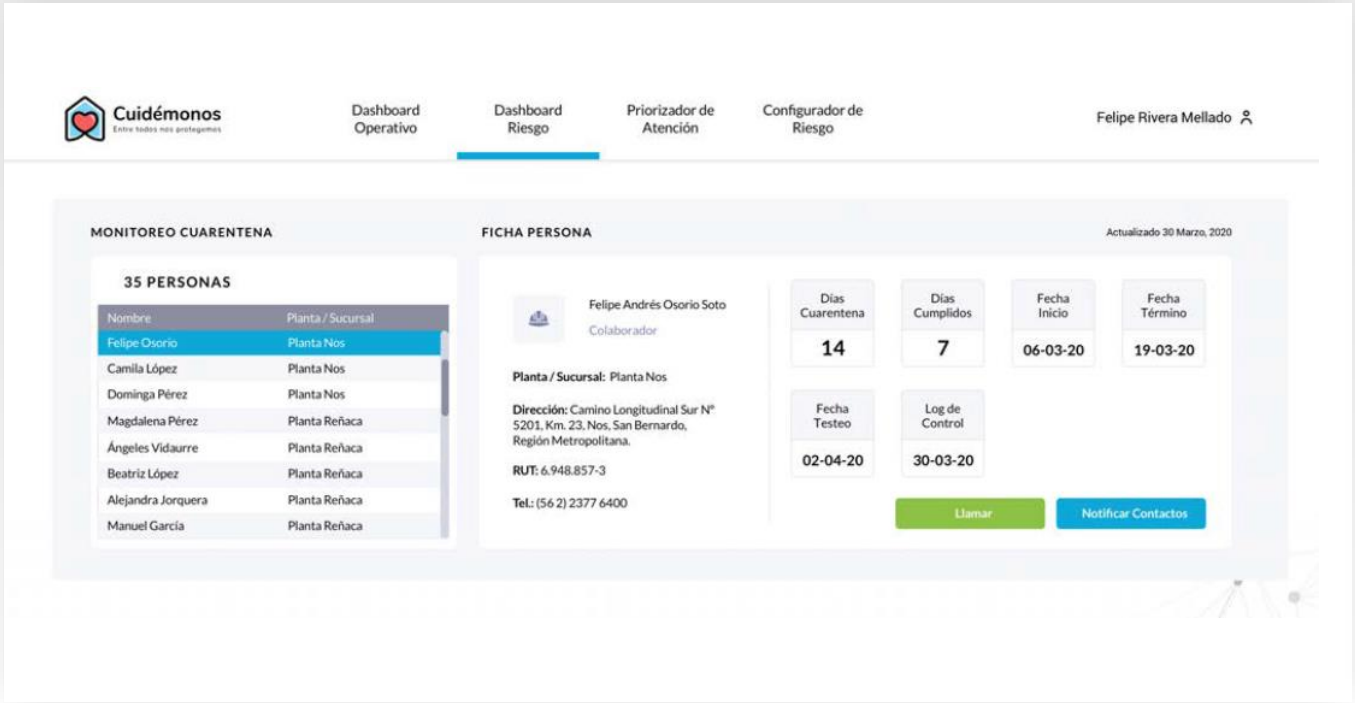
The project has the backing of the company **Unholster** that created the ‘Cuidémonos’ application that allows us to:

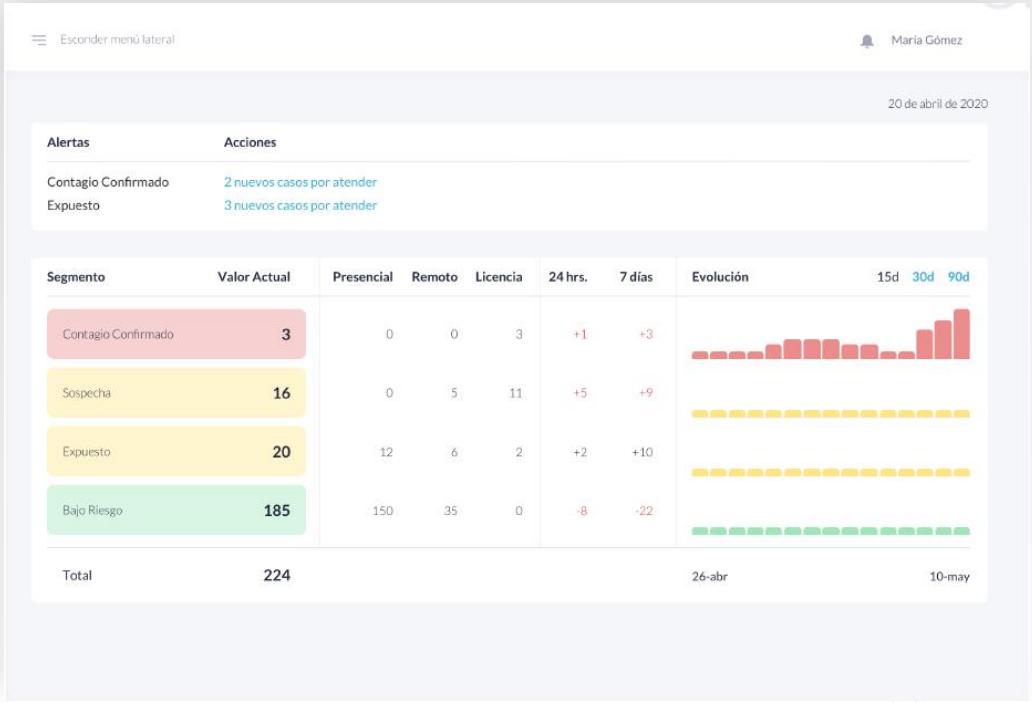
- Maintain information regarding the health conditions of medical staff.
- Have traceability of the shifts completed in order to detect early on medical staff in risk of infection.
- Monitor doctor quarantines.
- Visualize the information on the health conditions of medical staff whether they are infected, with possible infection, exposed to contact with an infected person, or at low risk.

# “Cuidémonos” App
# Unholster

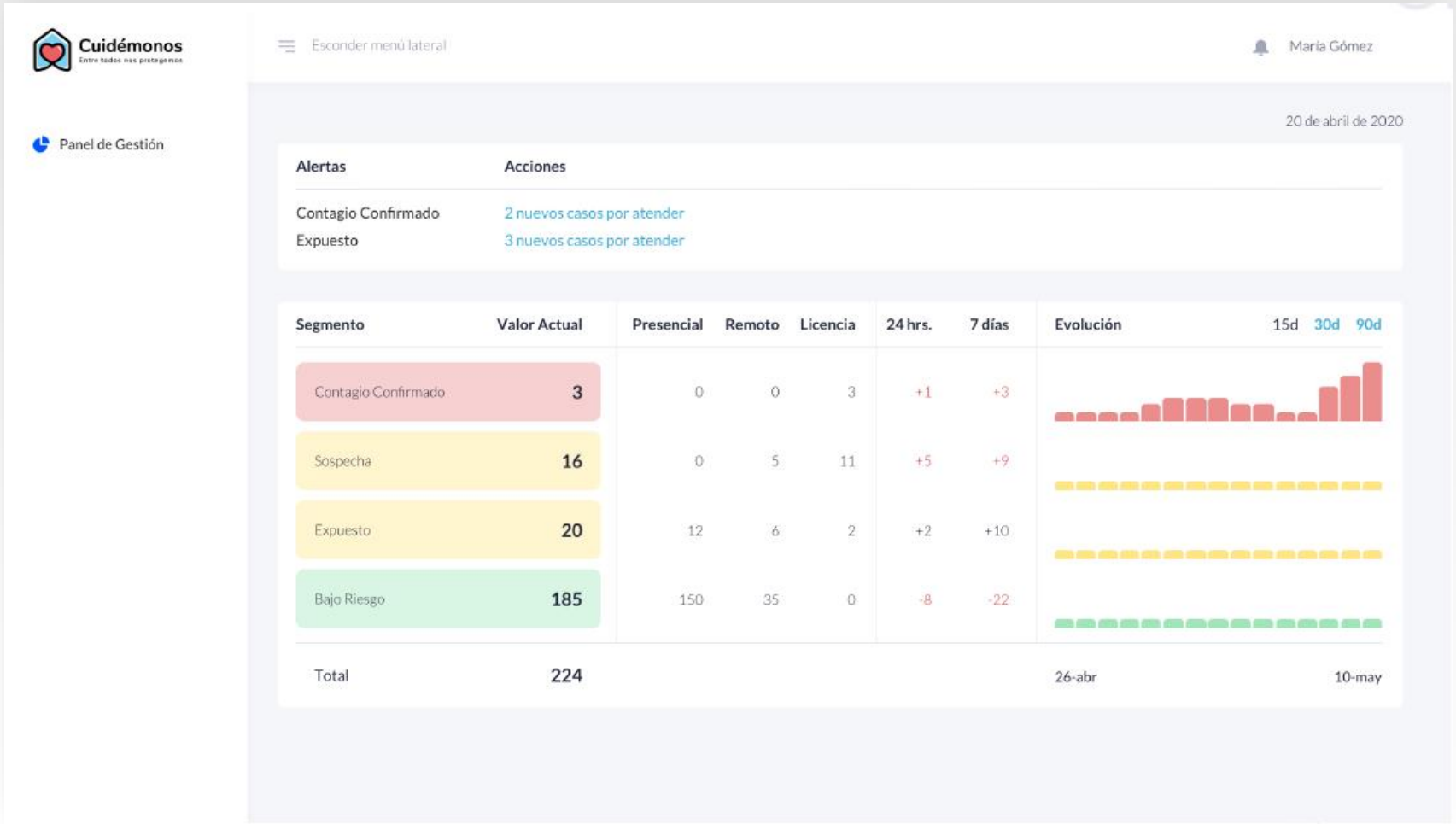



# “Cuidémonos” App
# Unholster



# “Cuidémonos” App
# Unholster



# TELE-ICU

## Dadneo Consortium

As the number of cases of infection among critical care staff rises, or staff members enter periods of protection/rest, the front-line presence of experienced intensive care staff will decrease.

- The Dadneo consortium has developed hardware and software that makes it possible to display online the most relevant information from a mechanical ventilator.
- This information can be monitored remotely by experienced professionals, thus offering support to front-line staff.
- Dadneo has made this technology available for this project. The on-line work can be incorporated into the shift schemes.
- The hardware is currently in operation at Hospital de Ñuble

# Strategic Group Testing of Medical Personnel

We propose PCR Pool Testing for preventive testing (screening) for healthcare teams.

**Idea:** Identify early on COVID-19 infections and cut quarantine times

**Pool testing:** Samples from multiple people (5 to 10) analyzed with a PCR kit

- Two-stage protocol: If a group is negative, everyone in the group is declared negative. If a group is positive, individual testing is carried out.
- Carrying out group tests allows us to: (i) multiply several times the testing capacity and (i ) deliver the test results quicker.
- The protocol does not effect the normal PCR technique, as shown in clinical trials carried out by the Universidad de Chile.

Further details in Iniciativa ISCI

*"Multiplying testing capacity: RT-PCR Pool Testing"* (www.isci.cl)

# TASK FORCE

## The Complex Engineering Systems Institute

**Marcelo Olivares**: PhD, ISCI Researcher, Academic at FCFM UCH
**Daniel Yung**: PhD, Postdoc ISCI & Universidad de Chile
**Víctor Bucarey**: PhD, Affiliated
**Sebastián Cerda**: ISCI Scientist
**Magdalena Badal**: ISCI Scientist  Sebastián Santana: ISCI Scientist

### Colaboran

**Leonardo Basso**: PhD, Director ISCI, Academic at FCFM UCH
**Denis Sauré**: PhD, Researcher ISCI, Academic at FCFM UCH

### Healthcare Advisory Team

**Dr. Eduardo Tobar**: Hospital Clínico UCH
**Dr. Juan Pablo Torres**: Faculty of Medicine UCH

### Empresas tecnológicas

Uholster (https://www.unholster.com/)

Intelligenxia (http://intelligenxiabg.com/)

Dadneo (https://www.dadneo.com/)

### Application

**Hospital Clínico Herminda Martín, Ñuble Region**
**Hospital Clínico of the Universidad de Chile**
**Complejo Asistencial Dr. Sótero del Río**

# CONTACT

**Lead Researcher**

Marcelo Olivares - maolivar@dii.uchile.cl

**Complex Engineering Systems Institute (ISCI)**

Leonardo Basso - ljbasso@ing.uchile.cl

contacto@isci.cl

www.isci.cl

ISCI INSTITUTO SISTEMAS COMPLEJOS DE INGENIERÍA