Review Article

After the Indian Ocean Tsunami: Singapore's Contribution to the International Disaster Victim Identification Effort in Thailand

G Lau,[1] *FAMS, FRCPath, DMJ (Path)*, WF Tan,[2] *BSc (Hons), MSc*, PH Tan,[1,3] *BDS, Dip For Odon (Melb), M Clin Den (Endodontology) (Lond)*

Abstract

This paper describes the international disaster victim identification (DVI) response mounted in Thailand, with particular reference to Singapore's contribution to this process, in the wake of the Asian tsunami of 26 December, 2004, which devastated parts of more than 10 countries in and around the Indian Ocean and claimed more than 200,000 lives. Although Singapore was unscathed by this natural calamity, over 30 Singaporean visitors were counted amongst the thousands of deceased victims, mostly in Thailand. The systematic application of forensic pathology, forensic dentistry, DNA profiling, and fingerprinting to human identification, especially of the bodies of various nationalities that were in advanced states of putrefaction, was crucial to the entire DVI process. The authors perceive that the resource implications arising from such a disaster, which is unprecedented in both its scale and reach in the international history of DVI, are immense. Forward planning, adequate funding and international cooperation are essential to mounting an effective response to any major mass disaster of the future.

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Introduction

The now much-discussed tsunami of 26 December 2004, attributed to a massive undersea earthquake (magnitude of 9 on the Richter scale) that occurred off the coast of Banda Aceh in Sumatra, is reputed to have claimed the lives of over 200,000 in more than 10 countries, mostly within, or on the fringe of the Indian Ocean although its effects extended as far as Somalia and parts of the Middle East.

In its wake, some 200 to 300 Singaporeans were initially believed to be either missing or uncontactable in Thailand alone. Over the course of the ensuing weeks, relentless legwork by the Singapore Criminal Investigation Department (CID) reduced these estimates. At the time of writing, approximately only 30 Singaporeans were confirmed either dead, missing or uncontactable, worldwide; the corresponding figures for Thailand (where most of the local casualties occurred) were 7, 12 and 3, respectively, amongst a total of some 4000 bodies of various nationalities (personal communication – Criminal Investigation Department, Singapore Police Force, 2005).

Despite being safely nestled in its unique geographic location, Singapore responded with alacrity to the massive scale of this international human tragedy, which was quite without precedent in terms of its magnitude and reach. In addition to the civil and military humanitarian relief efforts in Aceh province, Indonesia, and elsewhere, 2 successive disaster victim identification (DVI) teams were despatched to Thailand to assist in the international DVI effort, which had just commenced there.

[1] Centre for Forensic Medicine
[2] DNA Laboratory, Centre for Forensic Science
Health Sciences Authority, Singapore
[3] Singapore Armed Forces Medical Corps
Address for Reprints: Clinical Associate Professor Gilbert Lau, Deputy Director, Centre for Forensic Medicine, Health Sciences Authority, 11 Outram Road, Singapore 169078.
Email: gilbert_lau@hsa.gov.sg

Singapore's DVI Response

The first responders departed for Phuket, Thailand, on 31 December 2004. They consisted of about 20 DVI-trained police officers [including 3 officers from the Forensic Management Branch (FMB) of the CID], who were later supplemented by more officers. The Health Sciences Authority (HSA) contributed a forensic pathologist and a mortuary technician, who were subsequently joined by two DNA scientists. There were also 2 qualified forensic odontologists, 1 from the Singapore Armed Forces and another volunteer from private practice. The team was complemented by 5 emergency behaviour officers (EBOs), all clinical psychologists, led by a psychiatrist.

The relief DVI team arrived 2 weeks later and, apart from the police personnel and EBOs/psychiatric personnel, comprised a forensic pathologist, a technician and a forensic death investigator, as well as 4 dentists in private practice (of whom one was partially trained in forensic odontology; these worked under the close supervision of the experienced forensic odontologists). Each team spent 2 weeks in Thailand.

Disaster Sites

The damage inflicted by the tsunami was focal, but severe (Figs. 1 and 2). Much of Phuket island was intact, while the most extensively devastated areas were in Khao Lak (in a region known as Phang Nga, north of Phuket), Krabi and Phi Phi island.

Initially, the international DVI command (headed by the local Thai police general and co-managed by the Thai and Australian joint chiefs of staff) designated 3 principal disaster management sites.

Site 1 was in Khao Lak (more precisely, in Takuapa, a short distance north of Khao Lak), where the premises of a Buddhist monastery or temple complex were initially used to house and examine about 1000 bodies. Subsequently, another 1000 bodies were transferred from an adjacent holding site (also on temple premises in Bang Muang). Several hundred buried bodies were later exhumed and re-examined at this site, which catered to the Australian, New Zealand, Singapore, Dutch, French, British and Chinese DVI teams, distributed over what were eventually a total of 4 field mortuaries. The teams were later joined by Belgian, Nordic, German and Austrian personnel.

Site 2 was located off a beach in Thachatchai, on the north-western region of Phuket island, and was managed by the German and Austrian DVI teams. It was closed early in the first week of operation due to a paucity of unprocessed bodies on the island itself, with the result that these teams were transferred first to Bang Muang (where the Nordic teams were initially working) and then to Takuapa. Some weeks after the departure of the Singapore DVI team, a new field mortuary was established near this site, with equipment supplied by the Norwegians, in line with the decision to relocate the operations in Khao Lak to Phuket; this change was apparently effected with considerable logistical difficulty.

Site 3 was located in Krabi, where the Israeli, Japanese and Korean DVI teams worked uneventfully.

Co-ordination of Disaster Site Management

Towards the end of the second week of the operations, the provisional international DVI command, which included the DVI commanders of the various international DVI teams, was replaced by an executive committee to consolidate the administrative and logistical co-ordination of the work being undertaken at the various disaster sites. Overall command still lay with the Thai authorities and both the Thai and Australian joint chiefs of staff were retained. The remaining members comprised the various site DVI commanders and their deputies (instead of the commanders of the international DVI teams), as well as regional representatives members of the logistics and scientific (fingerprints, DNA and dental) sub-committees.

The Singapore DVI Teams

In accordance with international practice, the police led each team. Although the first team was despatched with the intended purpose of identifying Singaporeans, it was quickly and fully integrated into a concerted international DVI response, because there were only a few Singaporeans amongst the thousands of deceased victims whose bodies were in advanced states of putrefaction. In the event, the Singapore teams were essentially the only complete non-Thai Asian DVI teams at Takuapa (Site 1).

The Takuapa site was under the command of the Australian Federal Police (AFP). The Singapore teams worked alongside their Australian and New Zealand counterparts in the original (and the only air-conditioned and reasonably well ventilated) field mortuary, which later was also used by the British, Belgian and Nordic teams. The French and German/Austrian teams worked in separate tented field mortuaries which they erected. A fourth field mortuary, converted from a temple on the premises, later catered to the British and Nordic teams, who were re-assigned to it.

The DVI Process

The victim identification procedure consisted of 4 main stages, viz.:

(1) body tagging and bagging, (2) fingerprinting, (3) forensic pathology, and (4) forensic dentistry.

The bodies were, of course, refrigerated both before and

after the procedure, and then embalmed for repatriation. Initially, the international DVI teams were restricted to processing the bodies of victims presumed to be foreigners, as pre-classified by the Thai authorities, while the Thai teams examined the bodies of those presumed to be deceased Thai nationals.

1. Body Tagging and Bagging (Fig. 3)

The labelling of each body with a unique identifying number, followed by its placement within an impervious body bag, was undertaken by Singaporean CID officers, working alongside their British counterparts. With the consensus of the international DVI commanders, the provisional international DVI command devised a system of labelling which comprised the following sequence of numbers: international telephone country code–site number –(5-digit) body number (e.g. 65–1–00123). We observed that the bodies which had been labelled before this system was implemented bore only 3-digit body numbers.

2. Fingerprinting (Fig. 4)

Fingerprinting of the highly decomposed bodies, which almost invariably showed extensive post-mortem skin desquamation or peeling, posed a considerable challenge to the police officers assigned to the task. These officers were either fingerprint experts in their own right or experienced SOCOs. The "powder technique", which entails the careful and gentle application of dry dusting powder to the fingertips with a brush, accompanied by the frequent wholesale de-gloving of the loose skin around the distal portion of the fingers containing the unique skin ridges, was employed with considerable success.

3. Forensic Pathology (Fig. 5)

Each labelled and fingerprinted body was examined by a 4-member DVI team, comprising a forensic pathologist, an anatomical or mortuary technician, a scribe (usually a police officer; in the second Singapore team, alternately a police officer or a forensic death investigator), and a photographer (usually a scene-of-crime or FMB officer).

In most mass disasters, the purpose of the post-mortem (PM) examination is to obtain clues which might lead to a positive identification of the deceased victims, rather than to establish the cause of death (which would largely have been due to drowning or multiple injuries engendered by the tsunami). A simplified procedure was therefore established to expedite the examination of what were literally thousands of highly putrefied bodies. This procedure comprised the following steps:

(a) The body was conveyed to the mortuary from the fingerprints section.
(b) The scribe received and signed the tracking form.
(c) The pathologist and scribe confirmed the body number, using the pink PM DVI form (as prescribed by Interpol).
(d) The body number was photographed.
(e) The technician removed and rinsed or washed the clothes (if any) to display their respective brands, sizes, colours and designs; the attire was then photographed and recorded.
(f) All jewellery and personal effects were washed, photographed with the body number, described and recorded; they were then placed in a sealed bag which, in turn, was placed within the body bag.
(g) An external examination of the body was carried out; the sex, height, estimated age (mostly impossible), tattoos, scars (traumatic and therapeutic), physical abnormalities and other characteristics were recorded.
(h) A midline abdominal incision was made to check for the presence or absence of the gallbladder, appendix, female internal genitalia, and for evidence of other previous operations. In this respect, the first author encountered instances of previous laparotomy, laparoscopic cholecystectomy and total hysterectomy and bilateral salpingo-oophorectomy. Sometimes, advanced post-mortem tissue degradation rendered it difficult to establish the presence of an appendix, although an appendicectomy scar would have helped.
(i) Other incisions were made, where necessary, e.g., where there was a midline sternotomy scar, indicating previous cardiothoracic surgery, or other surgical scars associated with total hip or knee replacement surgery.
(j) Evidence of any other identifying disease was sought and recorded.
(k) The technician removed the mandible to facilitate subsequent forensic dental examination.
(l) The body was finally conveyed to the dental section.

It was perhaps fortunate that the already complex situation was not compounded by issues of criminality, which, for example, might feature in a terrorist attack. In such a scenario, fragmentation of the bodies resulting from an explosion would render body retrieval and reconstruction, let alone identification, immensely difficult.

4. Forensic Dentistry (Fig. 6)

Forensic Odontology comprised 2 sections: dental examination and dental radiology. Teams of paired odontologists, supervised by a senior odontologist ("super dentist"), worked in these sections. To facilitate dental examination, facial dissection was performed. Bilateral incisions were made from the upper anterior neck to the back of the ears. The skin and underlying tissues were then reflected upward over the face to expose the maxilla and mandible.

Fig. 1. A beach resort in Khao Lak that was devastated by the tsunami.

Fig. 2. A marine police patrol craft washed more than 0.5 km inland from the shore.

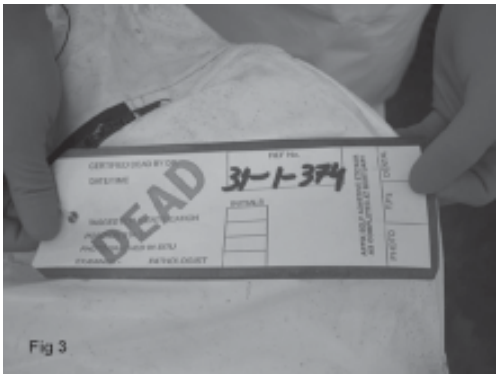

Fig. 3. Body tagging with a unique identification number.

Fig. 4. Fingerprinting.

Fig. 5. Post-mortem examination of the putrefied body of a victim.

Fig. 6. Forensic odontologists at work.

At the dental examination section, 1 dentist (examiner) examined the dental remains, while the other (scribe) documented the results. Up to 4 teams could work in this section at any one time.

The teeth were first brushed clean for photographic documentation. Three Polaroid® photographs were taken, consisting of a frontal view of anterior teeth, and occlusal views of the upper and lower jaws. These photographs were labelled with the body number.

The dental examiner-scribe team then proceeded to produce the post-mortem dental record. The dentist examiner carried out the dental examination and called out the finding for every tooth, while the dentist scribe charted them in the pink DVI form using the Interpol dental

charting system.

The Interpol dental charting system employed the World Dental Federation (FDI) tooth numbering system, which divides the dentitions into 4 quadrants, numbered 1 to 4. The upper right quadrant was 1, upper left 2, lower left 3 and lower right 4. Teeth were numbered from the midline to the posterior, e.g., central incisors were #1, canines #3 and third molars #8. Teeth were denoted by a 2-digit code (the quadrant and the tooth). Details of the Interpol post-mortem charting system are summarised in the Appendix.

During the dental examination, teeth that might have received root canal treatment were identified for further radiographic investigation. Two untreated teeth were then selected for extraction. These teeth would provide a source of genomic DNA for DNA profiling. Although molars were preferred because of their larger pulps, other intact teeth were also selected. If such teeth were not available, such as in the elderly or infants, a segment of femur shaft bone would be removed instead by the pathologists or anthropologists.

At the dental radiology section, odontologists also worked in pairs. One dentist would x-ray the dental remains ("dirty" dentist), while the other ("clean" dentist) labelled each exposed film with the body number before dispatching them for processing. Two bite-wing radiographs, 1 for each side of the jaws, and other additional radiographs were taken.

Once the films had been processed, they were checked for quality. Any further information revealed by the radiographs would be recorded in the pink DVI form. If necessary, radiographs were repeated. Once the radiographs were deemed satisfactory, the teeth identified earlier for DNA profiling would be extracted, placed in sterile plastic containers, and sent to a DNA collection area. The "super dentist" would carry out a final check of the documents and radiographs, before releasing the body to the refrigerated containers.

Although forensic odontology was a laborious and time-consuming process, it yielded information that led to the relatively quick identification of a number of victims in the early stages of the DVI process. Among them were the bodies of 2 Singaporeans, including a physician, whose recovery in February and April 2005, respectively, were reported by the local media.

Documentation

As previously indicated, PM data collected from forensic pathology and dentistry were collated and recorded in the pink DVI forms prescribed by Interpol. Concurrently, ante-mortem (AM) data relating to the deceased victims' sex, age, physical attributes, medical history, dental records, and the next-of-kin's DNA profiles were recorded by other staff in yellow DVI forms. Both the PM and AM data were subsequently reconciled with the aid of a computer software system (Plass Data©) and the prescribed white DVI forms.

Data Reconciliation

A DVI information management centre was established to facilitate the onerous work of reconciliation, that is, the matching of AM and PM data. It was located on the premises of a Thai telecommunications organisation. The data centre was operated by an international team of forensic dentists and DNA and fingerprint experts, together with supporting staff, led by the Australian police. Before their return, the Singapore DNA and forensic dental experts ensured that all available AM data were properly transcribed in the relevant sections of the DVI forms for subsequent data entry. This probably contributed significantly to the early identification of the Singaporean physician.

Dental Identification in Mass Disasters

The teeth contain clues that may be used to build a dossier on the age, social habits and dental history of a person. Changes brought about by pathology and the intervention of dentists also result in the mouth becoming unique to the individual, and provide a library from which information may be extracted.

The adult dentition is composed of 32 teeth, each possessing 5 surfaces. The many combinations of missing teeth, caries, fillings and prostheses involving these 160 surfaces (estimated to be more than 2 billion) greatly decreases the likelihood of any 2 adults having identical mouths. It has been shown that even identical twins do not have identical dentition.[1]

Dental structures are the hardest and most resilient tissues of the human body. No matter the manner of death, dentition can survive most post-mortem events that can disrupt or change other body tissues.[2] In situations where bodies are disfigured beyond visual recognition, such as in delayed recovery, teeth remain a reliable means for establishing identity.

In dental identification, a person's dental records made before death is compared to the dentitions of the unknown deceased. The more accurate and complete the dental records are, the greater the likelihood of a positive identification. Individuals with numerous and complex dental treatment are easier to identify than individuals with little or no restorative treatment.

Many of the tsunami victims in Thailand were European tourists. Most presented with expensive dentistry in the mouths, ranging from gold inlays (fillings), crowns and bridgework, to dental implants. One had a diamond-studded

front tooth. The prospect of dental identification for these victims was good.

There is no minimum number of concordant points required to arrive at a positive dental identification. Unlike fingerprint identification, which is achieved by a minimum number of concordant points, dental identification is based on an evaluation of the type and rarity of dentistry. It is possible to have a positive identification based on a single unusual dental feature.[3] However, caution should be exercised when there is such minimal evidence. The identification must also be justifiable in a court of law or in peer review.

The dentition can also provide information on an individual's likely place of residence and socioeconomic status. This may be observed from the treatment techniques, and the quality of work and dental materials used to restore the deceased's dentition, which are usually influenced by the affluence of the country. Although these observations cannot pinpoint a particular country, they can suggest a probable geographical area.

Some of the tsunami victims had received dental implant treatment. The implant systems used were of popular European and Scandinavian designs, suggesting that the deceased might have been foreign nationals. This inference assumes that the deceased had their dental work done in their country of residence.

Most of the bodies examined at the Wat Yan Yao mortuary presented with pink teeth, a post-mortem change often seen in water-immersed victims. It is believed that a rupture of capillaries in the hyperaemic pulps and the release of red blood cells into the dentinal tubules causes the teeth to acquire this pink discolouration.[4] Pink teeth are analogous to post-mortem lividity stains at the most dependent part of the body. Some drowned victims may have spent some time in a head-down position.

Because of the resistance of dental tissue to environmental assaults, teeth represent an excellent source of DNA materials.[5] DNA can be sampled from the dental pulp by crushing or sectioning the teeth.[6] DNA extracted from the teeth of an unidentified individual can be compared to a known ante-mortem DNA sample (e.g., extracted from stored blood, or material from a hairbrush or toothbrush etc.) or to the DNA of a parent or a sibling.[2] Two intact teeth, preferably the molars, were extracted from each body in Phuket for DNA analysis.

The post-mortem dental information gathered at the mortuary was forwarded to the Thai Tsunami Victim Identification Information Management Centre (TTVI-IMC) in Phuket, where it was entered into a database. Meanwhile, various countries were also gathering the dental records of their missing nationals. These datasets were also sent to TTVI-IMC, where a software programme called Plass Data© searches for matches between the 2 databases. This computerised reconciliation of ante-mortem and post-mortem data is carried out overnight

While there, the Singapore DVI team collated the dental records of 8 (out of 13) missing Singaporeans and entered them into the IMC database. Two Singaporeans have since been identified by their dental records. The Plass Data© programme eliminates a considerable amount of manual checking of dental data. It increases the efficiency of DVI by eliminating the unlikely and produces a list of the most likely matches in order of probability. The Plass Data© does not carry out identification; it only reduces the number of dental records to be compared, leaving the odontologists to make the final identification.

DVI needs time. Unnecessary haste in mass burials or cremation, without completing the required identification processes, results in later disputes and claims. The resulting emotional and legal repercussions exacerbate the suffering caused by the disaster.

The pressure to quickly dispose of human remains stems from the myth that corpses pose a serious public health risk. The World Health Organization has established that dead or decomposed humans do not generally create a serious public health hazard, unless they pollute the sources of drinking water, or are infected with plague or typhus, in which case they may be infested with the fleas or lice that could spread the diseases.[7]

In Phuket, dental identification proved to be expeditious, accurate and cost-effective. At the time of writing, more than 1200 positive identifications had been made, the majority of which were by dental means. The work is continuing and is expected to last some months.

The Role of DNA Profiling in Human Identification

DNA profiling gained prominence in human identification following mass disasters in the last decade,[8-11] and is used in conjunction with fingerprints and dental records. The current technology for DNA profiling is the amplification of short tandem repeats (STRs). There are 2 commercial kits which permit the co-amplification of 15 genetic loci in one reaction. The executive committee in Phuket chose the AmpFlSTR Identifiler kit (Applied Biosystems, USA) comprising the 15 genetic loci, D8S1179, D21S11, D7S820, CSF1PO, D3S1358, THO1, D13S317, D16S539, D2S138, D19S433, vWA, TPOX, D18S51, D5S818, and FGA. The sizes of the alleles of these genetic loci ranges from 100 bp to 350 bp. The discriminating power for an individual at the 15 genetic loci is approximately 2×10^{17}. There are 2 approaches to identification by DNA profiling, direct and familial matching.

Direct Matching

DNA profiling may be used in direct matching, in the same manner as fingerprint and dental records, in which an ante-mortem DNA profile is compared to a post-mortem DNA profile and, if there is an exact match, serves as identification of the deceased person. However, except for criminal offenders who have their DNA captured as part of their criminal records, most individuals will not have ante-mortem DNA profiles. However, it is still possible to obtain an ante-mortem DNA profile of the victims through an analysis of their personal effects, such as toothbrushes, hairbrushes, combs and shavers. Every day, traces of one's biological materials are shed onto these items, and the DNA profiles developed from them can serve as ante-mortem records. Nine families submitted a total of 28 items comprising a small bolster, shavers, combs, hairbrushes, and miscellaneous items such as hairbands, hairclips and lipsticks belonging to 11 persons missing after the tsunami in Phuket.

Ten different DNA profiles were successfully developed from the bolster and shavers, and a good yield came from the roots of hairstrands caught in the bristles and teeth of hairbrushes and combs. The miscellaneous items were not used after a preliminary examination determined that they were not good sources of DNA. A DNA profile was obtained from a stain on the small bolster. The bolster belonged to a child in a family in which both parents were also missing. As we had the complete set of the maternal and paternal grandparents of this child, the DNA profile served as an important reference for her ante-mortem DNA records. Complete DNA profiles at 15 genetic loci were developed from the personal effects of both her parents, and they confirmed that the DNA profile developed from the bolster belonged to an offspring of that couple.

In direct DNA matching as in fingerprint and dental records, the authenticity of the ante-mortem record is of the utmost importance and, therefore, the ownership of the personal effects submitted by the family members must be absolute and verified by interviews with the family members. It is also important that in the collection of the personal effects, the person who collects these items does not touch the items with their bare hands lest they also leave sources of their DNA profiles on them. Two mixed DNA profiles were obtained from 11 of the items (toothbrush and hairbrush), indicating that the items had likely been used by 2 different persons. Though there is clearly a main contributor, who is interpreted as the "owner" of the item, and a minor contributor as the secondary source of DNA, they were not submitted as reference for direct matching. DNA profiles of their relatives were instead submitted for familial matching.

Familial Matching/Kinship

Familial matching is an alternative method of identification through DNA profiling, if personal effects fail to generate a complete DNA profile. It is also the only method of "indirect" matching available for victims without ante-mortem fingerprint and dental records.

Blood samples from the next-of-kin of disaster victims are always collected and used in conjunction with personal effects, as the ownership of the items cannot be absolutely confirmed. The relatives used for familial matching should ideally be the biological parents of the victim. In a normal paternity case, the maternal relationship is always assumed and the maternal allele in each of the genetic loci of the child is identified. The obligate paternal allele must be present in the putative father's profile. When all the alleles show inclusion, the paternity index (PI) is reported as the likelihood of the putative father being the biological father, versus a random man being the biological father. A PI >100,000 is easily achieved with 15 genetic loci and is accepted as conclusive proof of paternity. As the prior probabilities for paternity and non-paternity (on anecdotal evidence) are equal (i.e., 0.5 each), the PI is converted into a 99.99% probability of paternity (PP).

The first law of probability states that sum of probability of paternity (POP) and probability of non-paternity equals to one. Probability of non-paternity is therefore one minus probability of paternity (1-POP). The *odds of paternity* is also a ratio of the probability of paternity versus probability of non-paternity, i.e., POP/1-POP.

Bayes theorem defines the odds of paternity as a product of likelihood ratio (paternity index or PI) and prior odds (POP = PI x Prior Odds). The prior odds is the ratio of probability of anecdotal evidence for paternity versus against paternity. The anecdotal evidence for and against paternity is taken as equal and given as 0.5, cancels each out in the ratio for prior odds. Prior odds becomes equal to one. The *odds of paternity* become equal to the likelihood ratio or paternity index (PI) as it is commonly termed for parentage testing. Therefore PI = POP/1-POP. The equation becomes POP = PI/1+PI. The PI of 100,000 is converted into a 99.999 probability of paternity, although in practice, it is usually limited to 2 decimal places, i.e., 99.99%. For DVI purposes, the prior odds is the ratio of 1/10,000 for a person identified among the 10,000 victims who perished in the tsunami. It is not the sum of maternity paternity indices.[12]

Similarly, the maternal relationship cannot be assumed. Every single allele for each genetic locus obtained from the post-mortem sample of the victims is compared with both parents for inclusion. Instead of the PI, a likelihood ratio for both parents is calculated versus another couple being the

biological parents of the victim. The prior probability for DVI is one out of the total number of victims who perished in the tsunami in Thailand and is set at 1 in 10,000 as a conservative figure. The likelihood ratio is divided by the prior probability before it is converted to a probability of identity. Mutation and non-paternity can complicate the interpretation of results. The scientific committee in Thailand wisely decided that non-paternity would not be communicated to the family members, to avoid compounding their distress.

If both parents are not available, an option is to study the spouse of the victim with 2 children. The mathematics for this combination of relatives differs from that for both parents. The effectiveness of various combinations of relatives for identification varies, and the need for more relatives increases, when the relationship grows distant.

What about those people who lost most of their family, leaving behind a sole surviving member? Can the family be identified from this 1 person? The answer is: sometimes. It is not likely that a living child and a dead brother would share enough genetic similarity that 1 could pinpoint the identity of the other. But if the bodies of several dead siblings are recovered, then the evidence, by considering the cohort as a whole, could be much stronger. This approach is called the "lattice method". There are also many more families and extended families who died without any survivors, leaving behind no one to provide blood samples or personal effects. Nonetheless, there is a chance of identifying such a family if its members are found. If the bodies can be shown by DNA analysis to be related in a certain way, and if no other family in the vicinity has the same family tree, then we would know who they are, although this outcome is uncommon.

Difficulties and Limitations

The 2 methods of identification hinge on having obtained a complete post-mortem DNA profile, i.e., on obtaining the alleles at all 15 genetic loci. This outcome is not always possible. Degradation fragments the DNA, resulting in loss of the alleles and of discriminating power. The choice of post-mortem tissue for DNA profiling is critical to its success. Muscle samples collected from 2 tsunami victims (as a private case) failed to yield a DNA profile. DNA profiles obtained from bone marrow submitted subsequently matched perfectly with the blood samples of their relatives to generate a likelihood ratio of 1 in $3x10^6$, which, divided by the prior probability of 1 in 10,000, converted to a 99.7% probability of identification. Initially, the bone samples yielded a "partial" profile and required extensive optimisation before the full profile was obtained. Teeth are also an excellent source of DNA as the enamel and dentine shield the pulp from the harsh effects of the tropical heat and seawater, but the technique requires specialised sampling procedures.

It would be impossible for any one laboratory to handle the DNA profiling of all the post-mortem samples. While infrastructure and automation may reduce the workload, the sample-to-sample variability requires individual optimisation. In the aftermath of disaster, under the stress and strain of the circumstances, "contamination" of the samples can be seriously detrimental to the DNA profiling process. A large majority of the samples sent to the Beijing Genomics Institute from Phuket yielded mixed DNA profiles. This outcome highlights the great sensitivity of the technique, and the corresponding demands on the integrity of the DVI process if DNA profiling is employed as an identification tool. Mixed profiles were also obtained for samples recovered from the World Trade Centre site in New York City in the 11 September 2001 event, but this is expected, as the fuel explosion, collapse of the twin towers, fires, and the use of water and heavy equipment in the recovery effort would have led to an extraordinarily high level of friction and co-mingling of body parts.

The calculation of the probability of identity for several thousands of victims, with their different combinations of relatives, must be computerised for accuracy and speed. There are 3 software programs designed for mass disaster DNA kinship calculations. DNA View© is the cheapest, costing about US$15,000. It is a DOS program with no drop-down menu, thus requiring total familiarity with all its commands. The program frequently "hangs" in the current Windows platform, as it was written more than a decade ago. The second program, Bloodhound©, was used in establishing kinship relationships for the victims in the Swissair Flight 111 crash on 2 September 1998. It costs about US$250,000. Bloodhound© was able to conclusively identify all the 229 passengers and crew and reconcile the 1277 samples of human remains collected from the crash site with the 250 personal effects and 310 reference blood/buccal samples collected from family relatives. The Mass Fatality Identification System (M-FISys©), built specifically for about 3000 World Trade Centre victims (11 September 2001), costs US$3 million. It checks the quality of all the DNA profiles (standards, control samples, both post-mortem and ante-mortem) and gives a probability of identity of a victim with different groups of relatives, and is the most comprehensive software available. At the time of writing, both DNA View© and M-FISys© were in use in Phuket. The electronic data concerning the 10 personal effects and 24 family relatives' samples, and the quality control samples for the Singaporean victims have been submitted for uploading into the software in Phuket.

DNA profiling is the gold standard for DVI in mass disasters in which there is severe fragmentation of the

bodies, but it is an expensive and time-consuming method. Dental records and fingerprints are a quicker first-line method of identification when bodies are intact, as for the tsunami disaster, in which 2 victims were identified through dental records.

Discussion

The international DVI teams were subjected to operational demands not usually encountered in the course of forensic casework undertaken during normal circumstances. To begin with, even in the early stages of the process, the Thai authorities had requested for a round-the-clock DVI operation to expedite the examination of the victims presumed to be foreigners. Eventually, a compromise was reached, resulting in 3 overlapping shifts covering the periods of 0800 to 1600 hours, 1000 to 1800 hours, and 1600 to 2200 hours, with occasional days off. The considerable distance between Takuapa and Phuket (where the DVI teams resided) meant daily commuting to and from the DVI site by military transport (in the form of Superpuma and Chinook helicopters provided by the SAF until they were re-deployed to Aceh) in the early days. This travel mode was later replaced by 2- to 3-hour-long drives, each way. All this travel added to the strain and accumulated fatigue endured by the DVI teams.

The post-tsunami events during the first month of the DVI operations in Khao Lak and Takuapa were reminiscent of a textbook-like unfolding of a major mass disaster.[13] Out of the initial chaos and confusion, progressive order and a system of sorts gradually emerged. Cultural sensitivity was obviously crucial to maintaining at least a semblance of good international neighbourliness. Most (although not all) of the DVI teams displayed a good amount of this virtue in relation to their Thai hosts. It was perhaps fortunate that good sense seemed to prevail (at least on the surface), although behind-the-scenes manipulations were obvious and occurred against a backdrop of political overlays.

Understandably, pragmatism and common sense would have to prevail in such a situation. For instance, although both experience and best practice would dictate that none of the bodies should be released until all of them had either been identified or declared unidentifiable, to obviate the possibility of erroneous identification, the international political pressure constantly brought to bear upon the DVI teams and the command structure meant that any body identified by fingerprint, dental or DNA evidence that met the agreed Interpol standards would be released to the next-of-kin, once the administrative requirements were met.

Such cultural and political complexities, which can sometimes be vexing, may be expected in any mass disaster of such a magnitude that involves multiple nationalities. Indeed, the recent tsunami disaster illustrates the point that major mass disasters in the present era of extensive global travel for both business and pleasure, are likely to be international catastrophes of significant magnitude, whether caused by natural calamities or by human intervention (i.e., accidents or acts of terrorism).

This observation has important implications for Singapore. To date, local national emergency plans, covering both civil and national emergencies, have been based on the supposition that such incidents would occur locally and involve mainly Singaporeans. The post-tsunami events show that this assumption may no longer be tenable.

Accordingly, such disasters are likely to involve Singaporeans overseas. There must be provision for Singapore DVI teams to be sent abroad to assist in the relevant forensic work, as and when required. While we need an adequate reserve of forensic pathologists, not only to undertake the usual coronial casework efficiently, but also to mount an effective DVI response, either locally or overseas, forensic dentists and DNA experts are no less important human resources in any DVI response. Indeed, forensic dentists were initially in short supply in Thailand, and it is somewhat alarming that Singapore has only 2 trained and experienced forensic odontologists, of whom only 1 is a Singaporean. In a similar vein, more forensic DNA scientists have to be carefully selected and nurtured.

The scale of the tsunami-induced disaster also suggests that it is important to re-visit the estimates of fatalities incurred by any mass disaster, where the numbers of deceased victims may be overwhelming and may far exceed that of severely injured casualties. The Health Sciences Authority's Centre for Forensic Medicine is the nation's sole provider of forensic pathology services. Its mortuary can probably deal with up to 200 deceased victims, without seriously compromising its efficiency. When greater numbers have to be processed (as in the aftermath of the recent natural disaster, in which there were over 4000 fatalities in Thailand alone), well equipped and fully functional field mortuaries might have to be set up. Potential infrastructure in secure locations, away from public view and the international news media, has to be identified. These field mortuaries must have adequate ventilation and lighting, and reliable and safe supplies of water and electricity, as well as drainage.[13-16]

A computerised database would have to be set up to facilitate the matching of the ante-mortem and PM data, and this facility proved to be instrumental in the on-going work of data reconciliation at the DVI information management centre.

Moreover, given the likely cosmopolitan nature of such future events, provision may have to be made for foreign DVI teams to work alongside local ones if a mass disaster

actually occurs in Singapore territory. In Thailand alone, there were some 15 complete international DVI teams in all. In this respect, the Health Sciences Authority has established a memorandum of understanding with the Victorian Institute of Forensic Medicine in Melbourne, with the resultant framework for co-operation paving the way for mutual cross-border assistance in mass disaster management. Diplomatic clearance would be required for this purpose and the pathologists in these foreign teams must have medical qualifications recognised by the Singapore Medical Council for temporary registration.

Whether this arrangement materialises would be a purely political decision, but if it does, such activities must remain firmly under the jurisdiction of the relevant local authorities. An effective and efficient chain of command must be established. Flexibility, rather than mechanical adherence to established protocols or emergency plans (which seems to characterise emergency planning exercises) must be the order of the day. A consensus on where the ante-mortem and PM DNA profiling is to be carried out must be reached early on in any international DVI response.

Finally, DVI is both a labour- and capital-intensive venture. It requires adequate funding, which should be ring-fenced, for all its essential aspects and components. Indeed, it has been argued that the dire need for dedicated funding for disaster relief is often, if not usually, matched by its deficiency.[17] Ideally, special allowances should be granted to DVI personnel working overseas. None of them should have to move out of decent accommodation to a low-cost hotel because of the present economy drive, which happened in Thailand. Effective forward planning is essential to deal with the multifarious consequences of any major mass disaster.

Conclusion

DVI is both a challenging and stressful process for those who participate in it. This is true even in situations where the fatalities arising from a localised mass disaster of any nature number only in the low hundreds. It is decidedly more difficult when it takes on a truly cosmopolitan nature and claims the lives of thousands of victims. Forward planning, adequate funding, the availability of properly trained DVI experts and international co-operation are essential to mounting an effective response to any major mass disaster of the future, whether it is the consequence of a natural calamity or of human intervention.

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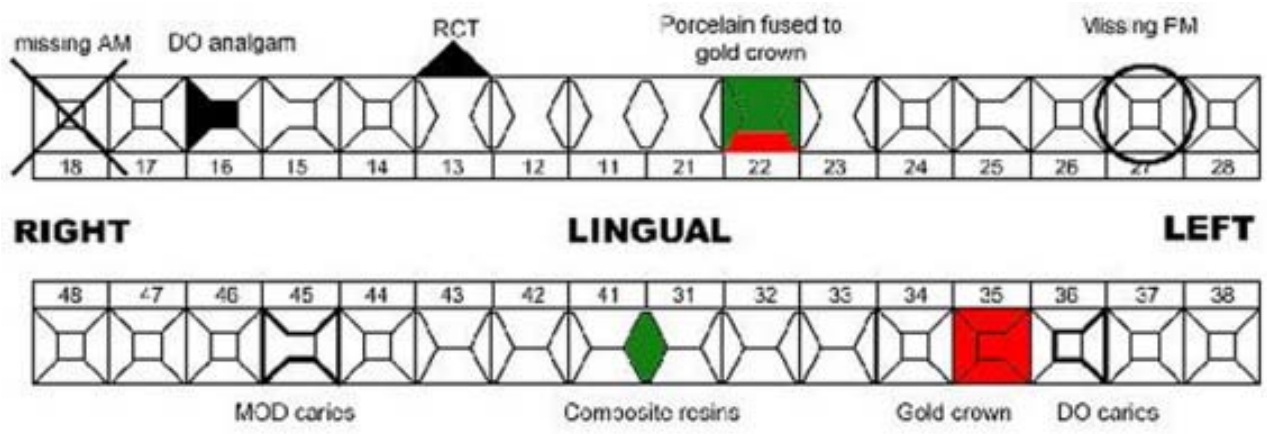
Appendix 1. The INTERPOL Dental Charting System.



Tooth Numbering System
Use FDI tooth numbering system.
There must be a notation for every tooth.
Commence charting from tooth 18 ending with tooth 48.
Sketch location and extent of all restorations and other conditions in the odontogram.
Surfaces are to be noted using the following capital letters:
M = mesial
D = distal
V = lingual
O = occlusal

Materials
Use the following colours:
Black = amalgam
Red = gold
Green = tooth-coloured material

Missing Teeth
Missing ante-mortem – place a large cross over tooth
Missing post-mortem – place a circle around tooth
Jaw sections not recovered are to be bracketed and labelled as "not recovered" on the odontogram and recorded as "not recovered" in the written notes.

Other Charting Codes
Cavity
Outline cavity in black.

Restoration
Block out restoration using the aforementioned colouring coding.

Root Filling
Block out "V" between upper and lower chart.

Fracture
Fracture of tooth material denoted by "#" symbol over affected tooth.

Crown
Colour tooth with appropriate material colour.

Dentures
Full maxillary denture F/-
Full mandibular denture -/F
Partial maxillary denture P/-
Partial mandibular denture -/P
Information pertaining to dentures to be recorded under the section of "Supplementary Details".

Bridge
Use appropriate material colour
Abutment – chart as for crown
Pontic – use a thick line from one abutment to the next abutment.

Unerupted tooth
Use capital letters "UE"

Space closed
Use of arrows → ←

Space opened
Use of arrows ← →

Tooth rotated
Use of a curved arrow under tooth

Retained root
For ante mortem retained root "RR"